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QUANTIFYING THE EFFECT OF HOUSING POLICY ON LAND USE CHANGE

EXPLORATIVE RESEARCH ON THE RELATION BETWEEN NATIONAL HOUSING POLICY AND PATTERNS OF LAND USE DEVELOPMENT

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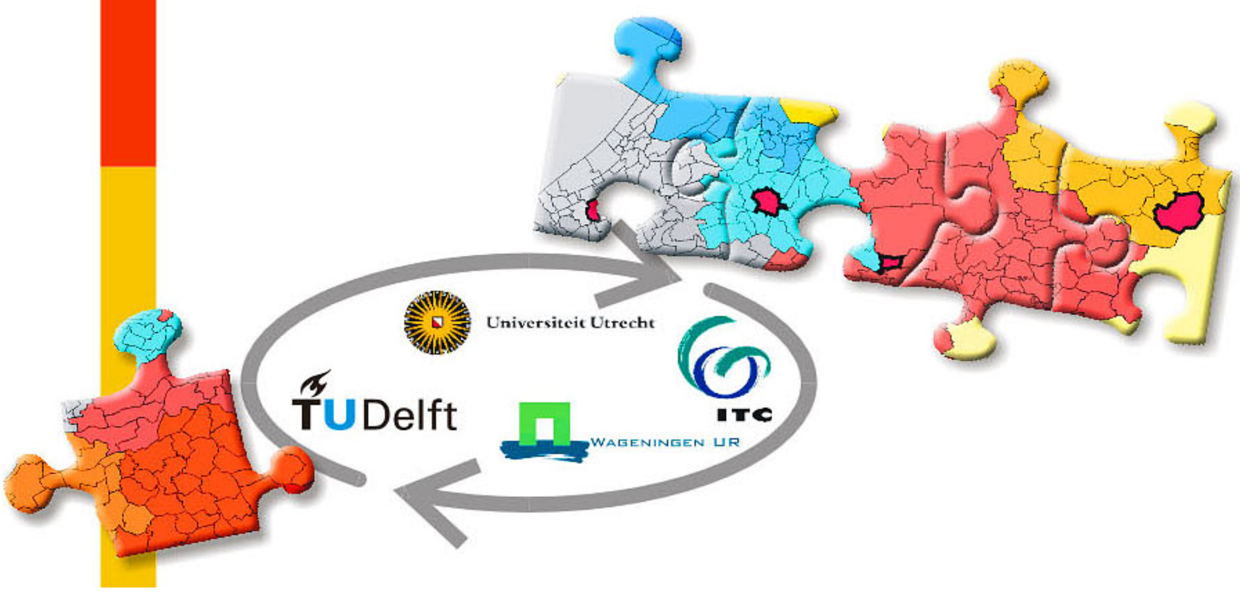

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EXPLORATIVE RESEARCH ON THE RELATION BETWEEN NATIONAL HOUSING POLICY AND PATTERNS OF LAND USE DEVELOPMENT

MASTER THESIS

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ABSTRACT

In the process of land use modelling and predicting future scenario's of land use, transition rules are derived from changes in land use observed in the past. This approach to land use modelling does not take the underlying driving forces of land use change into account. This research aims to provide a view at land use change from a different angle, in which the driving forces of land use change are the main focus.

In an attempt to modestly contribute to the current research questions in the field of land use modelling, this research analyses the effects of national spatial planning policy in the Netherlands on patterns of residential land use development at municipal scale. In the perspective of this research the expected results derived from the policies have a leading position.

An analysis of spatial planning policy provides an overview of important policies that are expected to influence residential land use development. For these policies, the expected influence on residential land use development is formulated. Inspired by literature from land use and land cover research, metrics are formulated to test if these expected patterns of residential land use could be observed. Based on the expected patterns of residential land use developments in areas with different policies, hypotheses concerning the values for the metrics are formulated to test empirically.

In order to test the hypotheses, residential land use developments that have taken place in the temporal range of this study, are distilled from land use datasets. The land use dataset for the starting year is compared to a dataset for the last year of the timeframe of this research. This comparison results in a retrospective overview of the changes of residential land use in the study period. In this process, scale considerations play a crucial role. For each of the calculations, an analysis of the scale effects is performed. Using the observed changes in residential land use, the values for the previously formulated metrics are calculated to be able to test the hypotheses.

The results for this research show that patterns expected based on the policy goals can clearly be found in the observed change of residential land use. While not all hypotheses are met in detail, the results meet the expectations in broader contours. Municipalities that have a pro-residential land use development policy tend to show more, larger residential developments than the municipalities with no such policy. Municipalities with a restrictive policy towards residential land use development on the other hand, show less and smaller residential than other areas. There is strong correlation between some of the metrics that have been developed for this research. This indicates that one or two of the metrics can be considered to be superfluous, and therefore omitted a similar study in the future.

In a case study the success of the Green Heart policy is quantified. This provides an insight in the performance of the Green Heart in comparison to other National Landscapes in the Netherlands. Additionally, this works as a test to find out whether the methodology applies in this study can be used at a more limited spatial extent.

Overall, this research shows that a different look at land use modelling can provide interesting insights in the driving forces behind land use change. The methodology applied in this research has proven to work well in general but there are certain learning points. Regarding research on policy as a driving force of land use change, this is only one of possible approaches. To gain a more fundamental insight in policy as a driving force of land use change, a quantitative research like here is ideally accompanied by a more qualitative research providing more insight in causalities.

ACKNOWLEDGEMENTS

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The support of my partner Miranda Ermen has been invaluable throughout the period that I have spent working on this thesis. Miranda seems to have found out my user's manual and she knows exactly at what moments she should support me and at what moments I prefer not to be disturbed. During the periods that in which I was deep in my thesis project, Miranda managed to watch over my well-being and all the practical matters in our lives.

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1 INTRODUCTION

1.1 Research Background

One of the initial ambitions of this MSc thesis research project was to make a modest contribution to one or several of the domains of land use modelling research where there are clear methodological or conceptual challenges. The orientation phase of the project consisted, therefore, of making a review of such challenges. The research challenges mentioned in the literature - and summarized below - can roughly be divided into four main categories: (1) challenges concerning data and data quality, (2) challenges concerning the modelling technique, (3) challenges concerning the theoretical foundation of land use change driving forces and (4) challenges concerning actor decision making in land use modelling.

The focus of this research project will be on the role of national policy (housing and spatial policy) in land use change. The results of the empirical work will be related to a few of the research challenges in land use modelling.

1.2 A summary of research challenges in land use modelling

Challenges in *data quality* that have been identified in research include:

- spatial scale issues including the combination of datasets with different spatial resolution (Agarwal et al., 2002; Heistermann, Müller, & Ronneberger, 2006; Parker et al., 2003; Schrojenstein Lantman, 2008);
- temporal scale issues with a focus on the non-linearity of event paths and different rotation cycles of phenomena (Agarwal et al., 2002; Guisan & Zimmermann, 2000; Heistermann et al., 2006; Parker et al., 2003; Schrojenstein Lantman, 2008);
- and issues concerning the thematic classification of data (Schrojenstein Lantman, 2008).

Challenges concerning *modelling technique* include:

- building an experimental frame to collect spatial data for modelling (Parker et al., 2003);
- empirical parameterisation and validation for high resolution models (Parker et al., 2003);
- integration of various methodologies from different disciplines in order to develop better simulation algorithms (Verburg, Schot et al., 2004);
- the use of theory of land use and land cover change and historical factors in models of land use change (Guisan & Zimmermann, 2000);
- development of methods to map multiple functions of land (Verburg et al., 2009);
- and an open source approach in modelling (based on the Linux principle: when enough people take a look at something, all problems will be identified (and hopefully tackled) someday) (Agarwal et al., 2002).

Challenges that have been identified concerning the *theoretical foundation of land use change models* are:

- understanding the multi-scale characteristics of land use systems (Verburg, Schot et al., 2004);
- understanding complexity of land use and land cover change (Agarwal et al., 2002; Parker et al., 2003);
- modelling the roles of institutions (Parker et al., 2003);
- understanding temporal dynamics of land use change (Verburg, Schot et al., 2004);

- quantifying neighbourhood effects and the effects of spatial autocorrelation (Guisan & Zimmermann, 2000; Verburg, Schot et al., 2004);
- understanding feedbacks of land use change on land use (Agarwal et al., 2002; Heistermann et al., 2006; Verburg, Schot et al., 2004);
- gaining a better understanding of urban-rural interactions (Verburg, Schot et al., 2004);
- and the influence of trade and competition on land use and land cover change (Guisan & Zimmermann, 2000; Heistermann et al., 2006; Verburg et al., 2009).

Challenges concerning *actor decision-making* in land use modelling are comparing different decision making theories and techniques and comparing models including these techniques with theory, practice and real world observations (Parker et al., 2003) and the identification individual response curves for actors (Guisan & Zimmermann, 2000). A more elaborated list of challenges in the field of land use modelling can be found in Appendix A.

After having introduced the research focus of this thesis project, we shall come back to these challenges and explain which of them will be (at least partially) addressed in the research.

1.3 Research Focus and Objectives

This research project will focus on a theme that is mainly related to the challenges concerning the theoretical foundation of land use change models. More specifically this research aims to provide better understanding of the influence of institutions on land use change patterns. While it is common practice in land use modelling to derive transition rules for land use change from the differences between two time-slices of land use in the past, this research has a fundamentally different approach. This research uses one driving force of land use change (institutions) as a starting point, and analyses what change in land use can be expected if this driver really has a influence on the change of land use. This is followed-up by an empirical analysis of land use change to investigate if the expected influence of this driving force can be quantified by the patterns of land use change that can be observed.

The objective of this research project is to identify the influence of formal institutions on the patterns of land use change in order to provide guidelines for handling institutional influence in future models of land use change. In this project formal institutions are assumed to be governing bodies that have an influence on the land use change process. These formal institutions can thus be local governments like municipalities or provinces. The focus of this research project will be on the national government being a formal institution formulating policy. The effects of this policy are assessed on a municipal scale. Patterns of land use change are changes of certain types of land use that occur in the same configuration (either spatial or non-spatial) in different geographical locations over time. It will be attempted to identify such patterns of land use change and provide insights on what influence formal institutions have on these patterns. With regard to land use types, the focus will solely be on housing, as – according to expert knowledge - this type of land use is among the most sensitive to legislation.

The main aim of this research is to investigate the influence of the impact of policy formulated by formal institutions, being the national government, on patterns of land use change at the municipal scale in the Netherlands.

The main hypothesis of this research is:
Patterns of land use change concerning residential areas differ between different municipalities in the Netherlands and this is caused by differences in national spatial planning policy for these municipalities.

In order to test the main hypothesis stated above the following research questions are formulated:

- What different visions have been dominant in spatial planning since the 1970's concerning housing areas?
- What patterns in land use change can be expected the based on the dominant spatial planning policies in the temporal frame of this study?
- What metrics can be used to characterise land use patterns for housing areas?
- What patterns of new residential land use can be identified in the study area?
- What observed differences in patterns of land use change can be related to differences in spatial planning policy?

The research project will touch upon the following of the land use modelling research challenged as summarized in section 1.1:

- Modelling the role of institutions: Modelling the role of institutions is the main focus of this research project. The aim of this research is to empirically analyse the effects of the steering by institutions on changes in land use.
- Understanding temporal dynamics: This research aims to touch at the temporal dynamics of spatial planning policy. Literature study is projected to provide insight in the temporal dynamics of spatial planning policy. The empirical part of this thesis will test if these temporal dynamics will allow the policy effects to be quantified.
- Feedbacks of land use change on land use: This research aims to give insight in land use as a result of social patterns instead. This is in contrast with the common practice in which land use is seen as a driver for land use change.
- Scale considerations: In order to quantify patterns of land use change experimentation with different cell sizes is performed in this research. On what spatial scale can we best identify patches of new residential land use? This is a balance of detail and efforts to minimise errors.
- Multi-scale characteristics of land use systems: How does the methodology in this research on residential land use as part of the land use system perform on different spatial extents? Quantifying the effects of national spatial planning policy on residential land use developments is carried out on national scale with municipalities as units of analysis. In a case study, this methodology will be applied to an area smaller than the entire Netherlands. This is reckoned to give an insight in the appropriateness of the methodology on different levels off spatial extent.

Within the process of land use modelling this research is focussed on the driving forces of land use change, the stage prior to the formulation of land use change algorithms. Furthermore, this research is limited to land use and does not take land cover or land function into account. Within land use categories this research solely focuses on housing. The institution that is subject to study in this research is the national government and the results are not expected to be valid for other institutions. The spatial units of analysis in this study are municipalities; the results are not expected to be valid at other spatial scales.

1.4 Structure of this report

In the following chapter, chapter two, literature on land use planning and metrics of land use change will be discussed. This leads to a set of expectations regarding the land use change to observe. Based on the literature metrics are formulated to quantify the patterns of land use change in order to evaluate the hypotheses. Chapter three will cover the methodology. This includes the research data and the methodology for the calculation. Firstly, this chapter will elaborate on the research data. Secondly, the chapter will focus on considerations regarding the calculation of the metrics and the actual calculation of the metrics. In chapter four, the research results are analysed. The chapter will take an in depth look into the results of the analysis and the hypotheses regarding the outcomes for the metrics are revisited. Thereafter, different groups of municipalities are investigated in more detail. Chapter five of this research is a case study, in which the methodology used in this research will be used to analyse a related topic on a smaller spatial extent. This case study will test the usability of the methodology used in this research on another spatial scale. In chapter six, the discussion chapter, the methodology and results are discussed. Finally the conclusion will revisit the main research hypothesis and findings are discussed.

2 LITERATURE REVIEW

The aim of this chapter is to formulate hypotheses on the expected patterns of new residential area and to formulate metrics to quantify these patterns.

The first section of this chapter will focus on spatial policy in The Netherlands. The goal is to derive a set of expectations concerning the patterns in which new housing has developed in the period 1993-2003 from the spatial planning policy dominant in the given timeframe. The policy analysis limits itself to policy that is expected to have a strong impact on housing development. The second part of this chapter, which focuses on measures of land use change, gives an overview of common metrics used to quantify land use change (patterns). The goal here is to formulate metrics that are suitable for this study inspired by the literature study. This chapter concludes with a synthesis of the first two sections leading to hypotheses concerning the patterns of new housing areas and to the metrics needed for assessing these hypotheses.

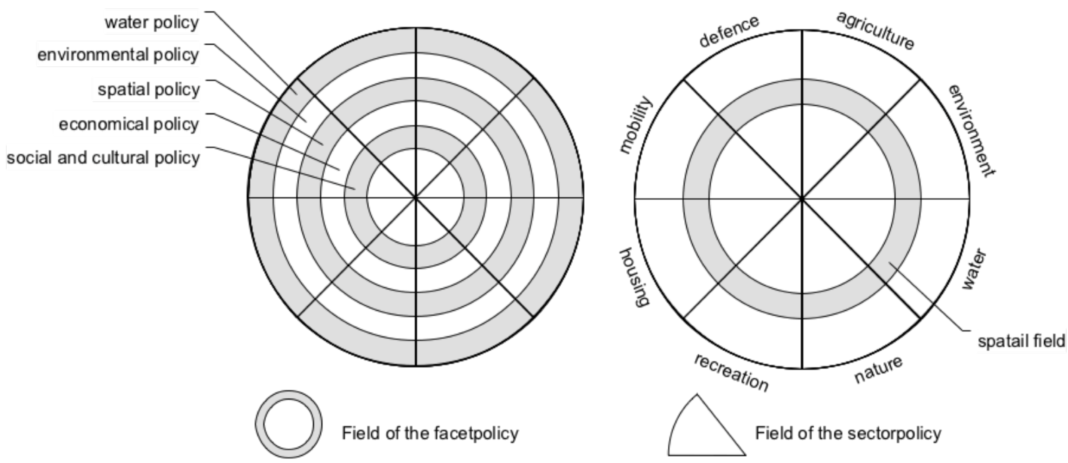
2.1 Physical planning in the Netherlands

Planning is a very broad field and it is far beyond the aim of this study to give a thorough overview of spatial planning in the Netherlands. This section starts off with a very brief orientation to the planning field. Thereafter, spatial plans that cover the spatial and temporal scale of this study are described.

2.1.1 Facet and sector policy

Physical planning obviously embodies a wider range of planning subjects than housing only. In literature, an analytical distinction is generally made between "sectorpolicy" and "facetpolicy" (Spit & Zoete, 2003). According to this analytical framework there are eight sectors in spatial planning policy: agriculture, environment, water, nature, recreation, housing, infrastructure and mobility, and defence. Independent of the sectors, there are facets of planning crossing the boundaries of all sectors in spatial planning: water policy, environmental policy, spatial policy, economical policy and social and cultural policy (Figure 2.1). This analytical framework has played an important role in Dutch national spatial policy but since the 1970's there has been an ever-louder call for more integrated planning approaches.

Figure 2.1: Schematic representation of facet- and sector-planning

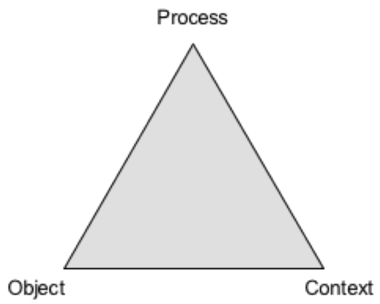


Based on: (Spit & Zoete, 2003)

The integrated planning approach aims at a synthesis of sectors and facets in spatial planning. In order to facilitate the integration of planning facets and sectors, visionary strategic documents are often developed for the long term that provide an integration framework for spatial plans.

Another important conceptual distinction is that between the so-called object component and the procedural or process component in any planning process. Together with 'context' (a broad category that includes any relevant spatial and temporal influences, such as political climate, economic situation, place-specific issues, et cetera), these components are referred to as the planning triangle: a conceptualization of the field of work of a spatial planner (Figure 2.2) (Spit & Zoete, 2003). In this research project the focus will be on the object of spatial planning: residential land use development at a certain location. The context in which planning is evolving and the nature of the planning process are of less importance for this particular research.

Figure 2.2: Schematic representation of the planning triangle concept

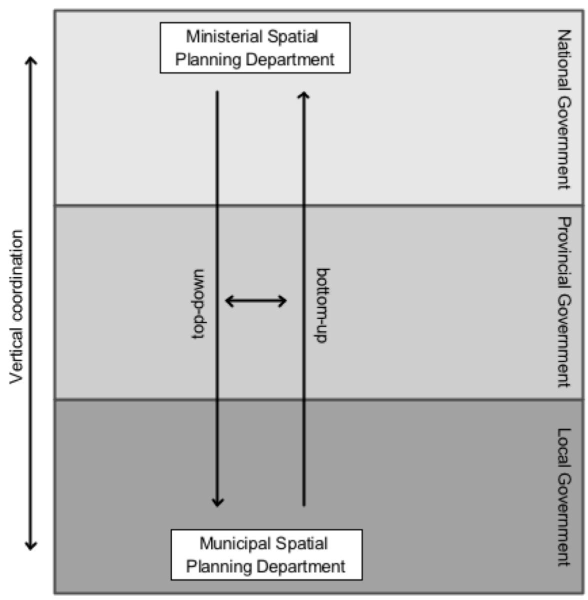


Based on: (Spit & Zoete, 2003)

2.1.2 Political levels involved in planning

Politically, spatial plans are made on different levels. The three main government levels involved in planning are national government, provincial government and municipal government. Over time, lower tiers of government have gained more influence: the planning system is moving from mainly top-down to bottom-up (Figure 2.3) (Spit & Zoete, 2003). However, there have always been local plans in addition to the national spatial planning policy.

Figure 2.3: Schematic representation of planning levels and direction of initiative



Based on: (Spit & Zoete, 2003)

During the 1970's, national planning documents generally had a high level of detail, including concrete target numbers (for example: number of houses to be constructed) and specific allocation of locations for development at the regional and even the municipal level. Internationally the Netherlands was seen as a country in which spatial development was largely planned through a (at first sight) clear hierarchy of national, regional and local plans and where what was promised on paper was really realized on the ground.

Starting in the 1980's the role of the national government became less directive in the planning environment. The national government started to act more and more as one of the players in the complex field (Cammen & Klerk, 2003; Spit & Zoete, 2003).

2.1.3 Focus in this study

As stated before, planning is a very broad field of academic study and social practice and only a very small part of it is of interest for this research. For the sake of narrowing down the focus of study, the following choices have been made.

- In the context of this research it is important to make a distinction between spatially explicit and visionary plans. For example, a spatial plan stating that economic development should be concentrated in the Randstad area is spatially rather vague or visionary. A spatial plan indicating that residential developments should be minimized in a certain area is more location specific. In this research the following distinction is made: spatially explicit plans are plans that appoint developments to specific locations and visionary plans are plans that are not bound to a certain location. As this research has the aim to measure the effects of planning decisions on the ground, only spatially explicit plans are taken into account.
- Because the study area for this research covers the entire Netherlands, the plans that can be analyzed by this study should cover the spatial scale of the study. Therefore only national plans can be taken into account.
- The plans should be influencing housing development, as housing is the type of land use that is analyzed in this study. Bontje (2003) states that the Dutch national urbanization policy can be seen as "one of the core elements of Dutch national physical planning policy". Considering this, the views on urbanization in the key national plans for spatial development covering the temporal frame of this study are examined. In the domain of sectorplanning this refers to the housing sector.
- Housing plans are often restricted by another spatially explicit sector of planning: nature policy. The Netherlands has a strict nature policy that strongly influences housing development, for example in the "Green Heart" area. Therefore restrictive nature policy will be taken into account.

Following the above choices, this section will now focus on the national, spatially explicit plans for housing development and for nature development and nature protection.

2.1.4 Urbanisation Policy

This research project will analyse patterns of land use change over the period from 1993 to 2003. This section describes the national planning policy that applies to that period. Because it takes several years for plans to become implemented in physical space after they are approved by the national government, we have to take a step back in time. In 1993, the national planning policy paradigm changed as the fourth spatial planning act extra (Vierde Nota Extra) was then accepted by parliament (Cammen & Klerk, 2003; Spit & Zoete, 2003; Wikipedia contributors, 2009b). In the early years of the study period, however, physical land use development was still influenced by earlier national planning policies, of which the third spatial planning act (which was finalized in 1983 after ten years of preparation) was the most recent (Cammen & Klerk, 2003; Spit & Zoete, 2003). In the study period the transition from the third to the fourth spatial planning act (extra) can be observed.

2.1.4.1 Third Spatial Planning Act

"Concentrated deconcentration" policy was the dominant urbanization policy in the Netherlands from the mid-1960's tot the mid-1980's (Bontje, 2003; Cammen & Klerk, 2003; Spit & Zoete, 2003). The initial goal of the "concentrated deconcentration" policy was to provide citizens with suburban housing in a green environment while preventing uncontrollable urban sprawl that might result from suburbanization pressure(Bontje, 2003; Cammen & Klerk, 2003; Wikipedia contributors, 2009a). In the context of "concentrated deconcentration" the policy term "Growth-Poles" was introduced in the third spatial planning act in 1974. These "Growth-Poles" are municipalities selected by the national government that should absorb the spill over growth from large cities. In total 17 municipalities were selected as "Growth-Poles" (Wikipedia contributors, 2009a).

After 1980 downsides of the "concentrated deconcentration" policy began to surface. Mainly middle and high-income households were moving from the large cities to the "Growth-Poles" (Bontje, 2003). This resulted in a decreasing basis for the services in the large cities. Furthermore, the "Growth-Poles" did not provide enough jobs for all new inhabitants leading to intensive commuter flows to the larger cities (Bontje, 2003; Cammen & Klerk, 2003; Wikipedia contributors, 2009a). Spatially the "concentrated deconcentration" policy led to concentrations of new suburban housing areas around the chosen "Growth-Poles".

2.1.4.2 Environmental awareness and compact city policy

In 1972 the report of the Club of Rome "Limits to growth" provoked discussion about the effects of economic growth on the natural environment (Bontje, 2003; Cammen & Klerk, 2003). The increasing car traffic was more and more seen as a hazard to the natural environment and human health instead of an indicator of economic prosperity (Bontje, 2003; Cammen & Klerk, 2003; Wikipedia contributors, 2009a) . In the 1980's environmental awareness got an extra impulse from the introduction of the concept of "sustainable development" (Bontje, 2003; Cammen & Klerk, 2003). A combination of this environmental awareness and the rising awareness of the need for sustainable development triggered a policy change towards a more intensive use of the space in the central cities. This policy is often referred to as the "compact-city" policy.

Spatially the "compact-city" policy implies an intensification of residential land use in existing city centres. This can be achieved either by replacing existing housing areas by housing areas with a higher concentration of houses or by transforming other types of land use within an existing city into residential land use.

2.1.4.3 Fourth Spatial Planning Act

In 1993 the fourth spatial planning act extra "Vierde Nota Extra or VINEX" was accepted by parliament (Cammen & Klerk, 2003). This planning act embodied the compact city policy. One of the core principles of VINEX was to build in and around existing cities as much as possible in order to preserve the vitality of the cities and to protect the environment. Large areas at the outskirts of existing cities were appointed by the provincial and municipal governments, within areas appointed by the ministry of Housing, Spatial Planning and the Environment, for absorbing future residential development (Cammen & Klerk, 2003; Spit & Zoete, 2003). In these areas (often referred to as "VINEX-locaties" or "VINEX-wijken"), large-scale housing development was planned for 1 to 1.5 million people (Spit & Zoete, 2003). In total, over one hundred VINEX-locations were agreed upon. Although many VINEX-locations were selected, 39% of the houses were supposed to be built within the administrative borders of existing cities (Wikipedia contributors, 2009b). The first VINEX houses were constructed in 1995 (Bontje, 2003).

From a spatial perspective, VINEX policy leads to two developments. On the one side, "compact-city" policy was continued: concentrations of housing in existing cities were intensified further and the transformation of areas with non-residential functions within these cities into housing areas continued. On the other hand large new urban land use zones were planned outside the existing cities (but actually neighbouring the cities) on the so-called VINEX-locations.

2.1.5 Nature policy

Apart from housing policy, there is a closely related policy that also is spatially explicit: nature policy. While being maybe less dynamic than housing policy, nature policy has a strong restrictive influence on housing policy as housing plans should not void the protected nature areas.

Dutch nature preservation policy consists of the following categories: National Ecological Network (Ecologische Hoofdstructuur, often abbreviated as EHS), Wetlands, National Parks (Nationale Parken), Natura 2000 and National Landscapes (Nationale Landschappen). Each of these policies will be briefly introduced below.

2.1.5.1 National Ecological Network

In 1990, the Ministry of Agriculture, Nature and Food Quality introduced the concept of a National Ecological Network (Ministry of Agriculture, Nature and Food Quality, 2005). It consists of a network of areas that are ecologically rich, linked to each other by connecting corridors. These connection corridors are intended to exchange between the ecosystems in the different national parks. The goal of the National Ecological Network is to preserve natural and ecological richness and diversity and to develop it by creating robust connections between different nature areas (Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2010a). The National Ecological Network policy is characterized by the "Nee, tenzij" (literally translated as "No, unless") principle. This implies that no spatial developments are allowed in areas that are part of the EHS, unless there are no alternatives and there is a major public interest at stake. In case no alternatives can be found, compensating the lost nature on another location can be one of the conditions for making an exception.

2.1.5.2 Wetlands

Wetlands are ecologically rich zones with water as a dominant feature, such as peat grounds or swamps that have unique natural values. The Ramsar treaty (or the Convention on Wetlands) from 1971 protects the wetlands and the species that live in these areas (Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2010d). The Ramsar treaty is worldwide; by 2009 158 countries had signed the convention. The Netherlands has 43 areas that have Wetlands status, which together cover over 800,000 hectares. Except one, all these Dutch designated wetland areas are subject to the European Birds Directive and thus part of Natura 2000 (Milieu- en NatuurCompendium 2010; natuurbeheer.nu, 2010).

2.1.5.3 National Parks

The National Parks are large nature areas (at least 1000 hectares) that house important ecosystems. The National Parks have a distinctive landscape and special plants and animals as inhabitants. Besides preservation and development of the nature, the National Parks policy focuses on nature-oriented recreation, education and research (Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2010b). Almost all National Parks are part of the

National Ecological Network or Natura 2000. In the platform "Samenwerkingsverband Nationale Parken", the National Parks work closely together in deciding on strategy and policy. The Ministry of Agriculture, Nature and Food Quality is responsible for the functioning of the National Parks as a whole (Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2010b).

2.1.5.4 Natura 2000

The European Union initiated Natura 2000 in order to preserve the wide spectrum of natural variation within the member countries. The initiative followed and combined two earlier EU directives: the European Birds Directive (adopted in 1979) and the European Habitat Directive (1992). The Natura Network Initiative bundled these two Directives in the Natura 2000 Networking Programme, which was implemented during 2004-2006 (Natura 2000 Networking Programme, 2010). The Netherlands has submitted 162 nature areas to gain Natura 2000 status (Dienst Landelijk Gebied 2010; Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2010c). The Natura 2000 areas in the Netherlands are almost completely covered by the National Ecological Network. Hence, there is a good planning relationship between the National Ecological Network and Natura 2000 (Milieu- en NatuurCompendium, 2010).

2.1.5.5 National Landscapes

National Landscapes are areas that have been selected for their cultural heritage and natural and landscape qualities. They are considered to be an appealing environment to live and work in and for recreation. National Landscapes are no preserved nature areas like the National Parks but the policy aims at preserving the distinctive qualities of these landscapes. This may mean, for example, that the allowed development of housing areas is limited to the needs for natural population growth. Hence, housing construction for incoming migration flow is not allowed. In the National Spatial Strategy (called "Nota Ruimte" in Dutch (Ministry of Housing, Spatial Planning and the Environment (VROM), 2010)) 20 national landscapes have been appointed, which are in total roughly the same size as the National Ecological Network (Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2005). Some of the current National Landscapes already had a protective status prior to the National Landscapes policy, like the Green Heart.

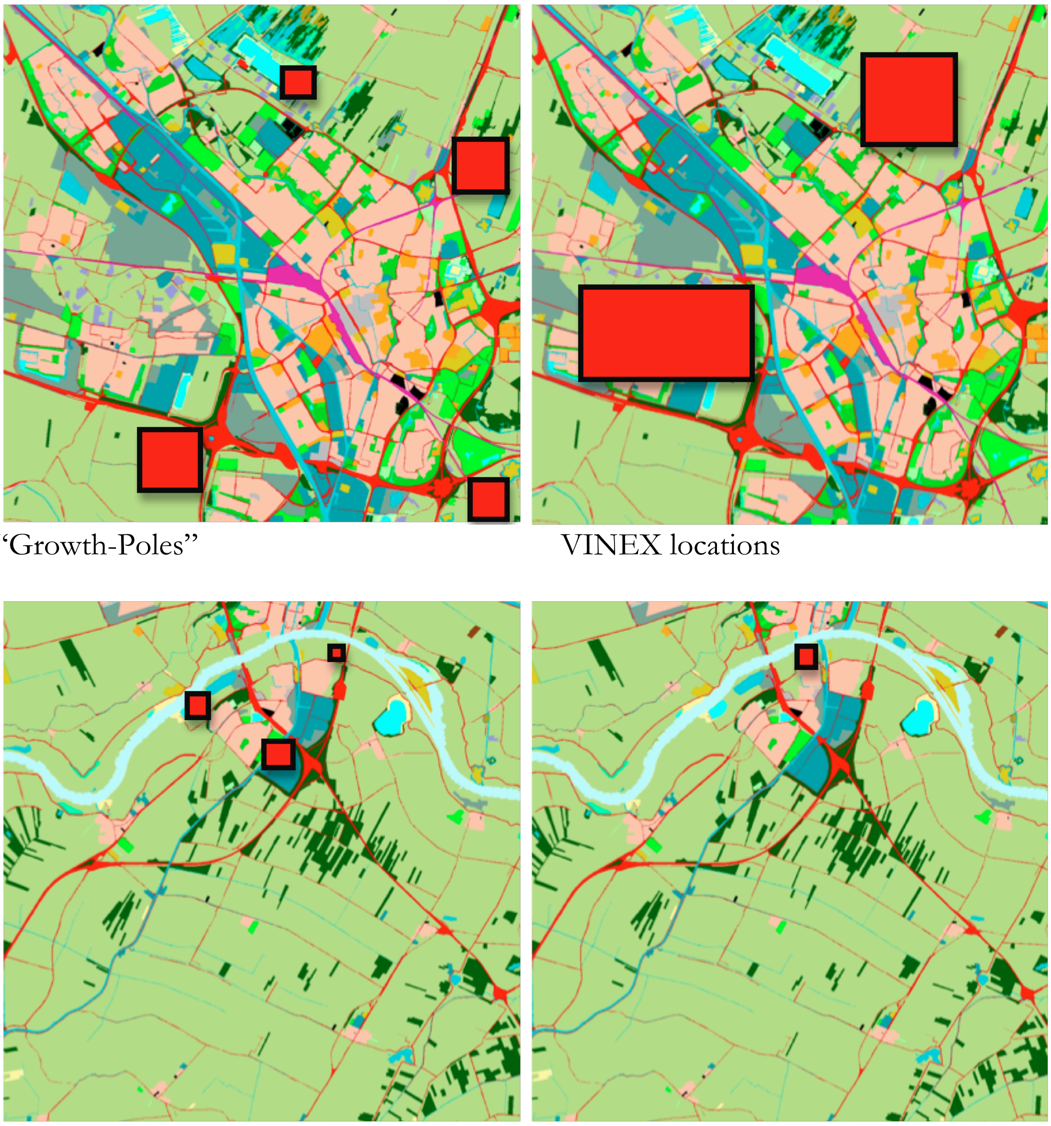
2.1.5.6 Relations between nature policies

As it has surfaced in the descriptions of the nature preservation policies above, the different preservation policies can co-exist and thus overlap spatially. The Naardermeer area for example, has multiple protected statuses including Natura 2000, National Ecological Network and Wetlands (Natuurmonumenten, 2010). Overall, two main approaches can be identified with regard to residential area development within nature preservation policies: "Build for natural growth" applies to the National Landscapes and "No, unless" applies to the other nature preservation policies. These two mechanisms have a substantial influence on the urbanization in selected regions.

2.1.6 Spatial implications of national policy

In the sections above spatially explicit spatial planning policy regarding housing was described. This kind of policy aims at spatially steering housing development to or away from certain locations. The vision represented by the national urbanisation policy tries to guide housing development in certain patterns and directions (which change over time). On the basis of these steering documents and agreements, stereotypical representations can be derived of the main paradigms implied in spatial and housing policy. The paradigm on urban expansion has changed over time from concentrated deconcentration to VINEX. “No, unless” policy with regard to housing applies to areas within the National Ecological Network; “Build for natural population growth” is the stereotype approach to housing in areas that are part of designated National Landscapes. Figure 2.4 visually represents stereotype images of housing developments in these four policies. Growth-Pole policy is expected to result in urban concentration around medium-sized cities in the Netherlands. VINEX policy is expected to result in large-scale but concentrated housing areas close to large and smaller cities. National Landscape policy is expected to cause only minor patches of urban growth in selected municipalities. Areas covered by the National Ecological Network are expected to show no urban development at all.

Figure 2.4: Visual representations of stereotypical policy patterns, red patches with a bold border represent areas of new residential developments



“Growth-Poles” — VINEX locations

National Landscapes — National Ecological Network

2.2 Metrics to quantify land use change

Quantifying spatial patterns in essence is describing the characteristics of a simplified (thematic) representation of (a part of) the world. Metrics are used to describe properties of features or groups of features on a map. A wide range of research has been conducted on how to quantify spatial patterns (Cushman, McGarigal, & Neel, 2008; Gustafson, 1998;

McGarigal, Tagil, & Cushman, 2009; Seto & Fragkias, 2005; Verburg, Ritsema van Eck et al., 2004). Ecological research on land cover has provided significant contributions to the understanding of how to quantify spatial patterns. More land use specific methodology has been developed in the research field of land use modelling.

2.2.1 Patch metrics versus surface metrics

Depending on the properties on the input data or map, different methods for quantifying spatial patterns can be used. Increasingly a distinction is made between patch metrics and surface metrics. Patch metrics are the classic approach to quantification of land use patterns. However, recently surface metrics have been introduced as an alternate approach to quantifying land use patters (McGarigal et al., 2009). Patch metrics use a map containing patches that have a certain value; these values are homogenous within the patches and the patches have crisp borders (like a block of houses). Surface metrics deal with continuous data, which do not have crisp borders; the values are only valid at certain points (like elevation). There also are examples of hybrid data models in which patches are used that can contain separate values for multiple types of land use (for example 20% urban, 60% agriculture and 20% water within one cell). The datasets used in this research are purely nominal; each area in the map has a certain land use class with a crisp border. Therefore only classic patch metrics are evaluated on their usefulness for this study.

2.2.2 Different types of patch metrics

In this study, the metrics to quantify land use patterns are categorized in five groups. These groups do not have very clear borders and they are solely intended as an ordering system. The five groups of metrics discriminated in this study are: metrics on map characteristics, metrics on frequencies of occurrence, metrics on size of features, metrics on shape of features, and metrics on neighbourhood properties of features. A metric on map characteristics can for example be the number of land use classes in a map. An example of a metric on frequencies is the number of cells of a certain class in the map. Metrics on size can describe the size of features of a certain map class. A metric on shape describes the shape of the features of a certain map class. Finally, neighbourhood metrics can for example, quantify properties of patches of a certain class in the context of their surrounding patches. Within these five groups metrics can either be global (describing multiple patches or features) or local (calculating a value for a single patch or feature). In the following section, common metrics from literature are described for these five groups. A more elaborated overview of metrics found in literature is included in Appendix B.

2.2.2.1 Metrics on map characteristics

Metrics on map characteristics are statistics that describe the map as a whole. Well known metrics on map characteristics are the number of classes (types of patches) in a dataset and descriptive statistics (mean, median, mode, standard deviation, etcetera) for these classes (Gustafson, 1998).

2.2.2.2 Metrics on frequencies

Global metrics on frequencies include:

- the number of patches of a certain land use or land cover class (often referred to as “number of patches”);
- the number of patches divided by the total landscape area (often referred to as “density of patches”);
- and “contagion” (the observed contagion over the maximum possible contagion for the given number of patch types) (Gustafson, 1998; McGarigal et al., 2009).

Local metrics on frequencies, common in literature, are:

- the "entropy *H*" (indicating the diversity of land use types within a single cell)(Ritsema van Eck & Koomen, 2008);
- the "species richness m" (the number of classes in a single cell, this ranges from 1 to n where n is the total number of classes) (Ritsema van Eck & Koomen, 2008);
- and the "dominance pmax" (the proportion of the largest function within a raster cell) (Ritsema van Eck & Koomen, 2008).

2.2.2.3 Metrics on size

Examples of global metrics on the size of patches are:

- "patch size distribution" which represents the distribution of patch sizes for a certain class (Ritsema van Eck & Koomen, 2008);
- "largest patch index" which represents the area of the largest patch divided by the total landscape area (McGarigal et al., 2009);
- and the percentage of the total surface that is considered to be a certain class (as the "urbanization degree" in Ritsema van Eck and Koomen 2007).

A local metric on size is the patch area (often in hectares) (Gustafson, 1998; McGarigal et al., 2009; Seto & Fragkias, 2005).

2.2.2.4 Metrics on shape

Metrics on shape are usually local as they refer to the shape of an individual patch or feature. These include:

- the "perimeter of an individual patch" (represents the length of the edge of a single patch) (Gustafson, 1998);
- "core area" (the portion of a patch that is further than some specified distance from an edge and presumably not influenced by edge effects) (Gustafson, 1998);
- "contiguity" (contiguity index assesses the spatial connectedness, or contiguity, of cells within a grid-cell patch to provide an index of patch boundary configuration and thus patch shape) (Gustafson, 1998; McGarigal et al., 2009; Ritsema van Eck & Koomen, 2008);
- "radius of gyration" (the mean distance between each cell in the patch and the patch centroid) (Gustafson, 1998; Ritsema van Eck & Koomen, 2008);
- "circularity ratio" (this metric indicates how much a shape deviates from its most compact form, a circle) (Ritsema van Eck & Koomen, 2008);
- "shape membership function" (this metric is more elaborate than the circularity ratio: it is also shape and size independent and has the additional advantage of quantitatively describing a number of shapes) (Ritsema van Eck & Koomen, 2008);
- and (the global) "area-weighted mean patch fractural dimension" (describes the degree to which the shape of an urban area is irregular or complex) (Seto & Fragkias, 2005).

2.2.2.5 Metrics on neighbourhood characteristics

Metrics on a global scale concerning the neighbourhoods of patches include:

- "patch cohesion" (used to quantify the connectivity of habitat as perceived by organisms dispersing in binary landscapes) (Gustafson, 1998; Seto & Fragkias, 2005);

- "mean Euclidean nearest neighbour distance" (the distance to the nearest neighbouring patch of the same type, based on shortest edge-to-edge distance) (McGarigal et al., 2009);
- "GISFrag" (GISFrag is an index that calculates the average distance to the nearest edge of all the pixels of the class of interest) (Gustafson, 1998);
- frequency of specific patch adjacencies (Gustafson, 1998);
- "contrast measures on neighbourhood patches" (the degree of contrast between neighbouring patches) (Gustafson, 1998);
- and the "Interspersion and juxtaposition index" (measures the extent to which patch types are interspersed) (Gustafson, 1998).

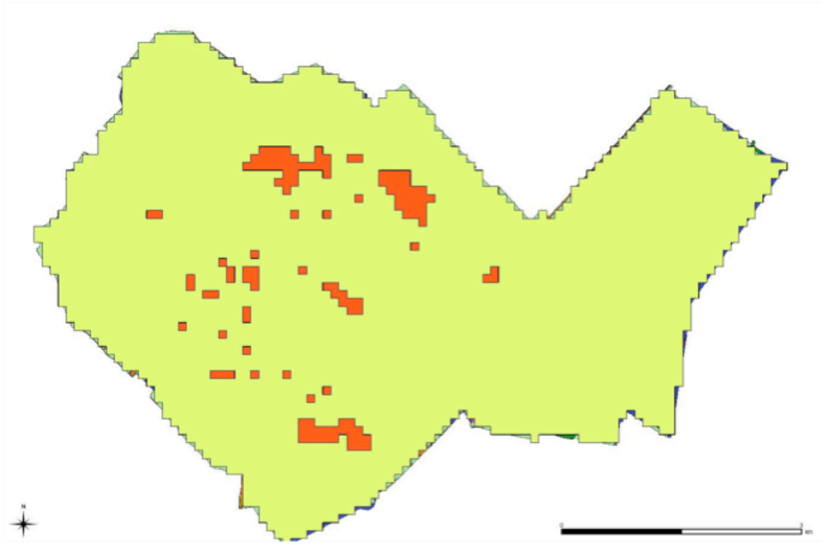
2.3 Selecting metrics to be used in this study

There is a huge variety of metrics to calculate land use (change) statistics out in the field. The metrics mentioned in the previous section are only a small portion of all metrics that have been described in literature. The temporal constraints connected to this research allow for only a very limited set of metrics to be used. Therefore, a small group of metrics will be selected to serve as inspiration while formulating the metrics to be used in this study.

2.3.1 Specific conditions for this research

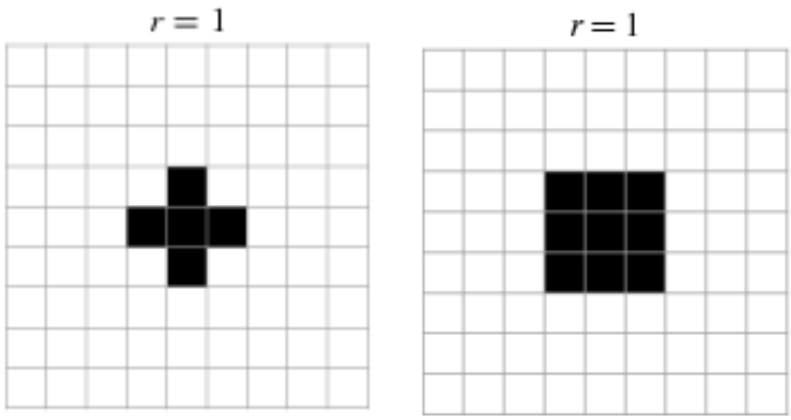
In this study we are comparing statistics for different areas, and not statistics within the same area. Therefore it is of importance that the statistics that are calculated can be aggregated per municipality so that the different municipalities or even groups of municipalities can be compared to each other. For the sake of comparison it is thus of importance that the values are relative, as absolute values are difficult to compare between very differently sized and shaped municipalities. The metrics used in this study are not calculated for the municipal land use maps of either of the two years of study, but for a map representing the delta (the observed change) for residential land use between the two years. Hence, all metrics describe the change of land use over time and not the situation at a given moment in time. This map of change is a Boolean map (a map based on two-value Boolean algebra in which cells can contain either of the following two values: 0 / FALSE or 1 / TRUE) containing cells that have changed to residential land use (value = 1) and cells that have not changed to residential land use (value = 0) between the two years (Figure 2.5). Hence, all measures are calculated for the observed change and not for the situation as it is.

Figure 2.5: Example of binary new residential area map, the red patches represent new residential land use



The patches can be cells or contagious groups of cells that have changed to residential land use. Contiguity of cells is determined using the von Neumann neighbourhood, a diamond shaped four-cell neighbourhood (Figure 2.6), with a range of 1. Besides the, The four-cell von Neumann neighbourhood is often applied in cellular automata, as is also the case for the eight-cell Moore neighbourhood (that will not be applied in this study)(Weisstein, 2010c; Weisstein, 2010d).

Figure 2.6: Von Neumann and Moore Neighbourhoods



von Neumann Neighbourhood　　　Moore Neighbourhood

Source: (Weisstein, 2010c; Weisstein, 2010d)

2.3.2 Potentially interesting metrics not suited for this study

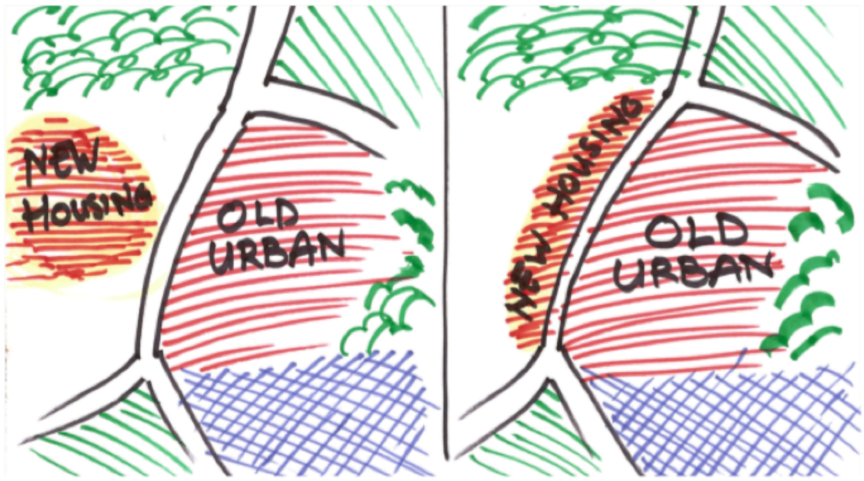
Because of the characteristics of the research data there are groups of potentially interesting metrics that are not suited to be used in this study.

The first group of metrics measures the number of different classes within a single raster cell. Examples of such metrics are "the species richness *m*", "the dominance pmax" and "the entropy *H*" (Ritsema van Eck & Koomen, 2008). Metrics describing diversity within single raster cells are potentially very interesting for this field of study as mixed land use is more and more a goal of spatial planning policy.

Secondly, metrics that assess the values of cells in the neighbourhoods of patches can be very interesting in the field of research of this study. Because this research focuses on residential land use only, thus no variety in neighbouring cell types can be observed, these metrics are not suited to use in this study. However, in further research these metrics could play an interesting role. Examples of these metrics are "Frequency of specific patch adjacencies" and "Contrast measures on neighbourhood patches" (Gustafson, 1998).

A third group of potentially interesting metrics is that of more complex metrics on patch area and shape. More complex metrics on patch size and shape include the "Patch Cohesion", the "Circularity Ratio", the "Radius of Gyration", "GISFrag", "Core Area" and the "Shape Membership Function" (Gustafson, 1998; McGarigal et al., 2009; Ritsema van Eck & Koomen, 2008; Seto & Fragkias, 2005). Although these metrics could provide very interesting insights in the shape and area of patches, these metrics are not suited to use in this study. This is because the mathematically most compact form (a circle) is not necessary the spatially most compact form (see Figure 2.7). If the research would be conducted on a smaller scale (one municipality for example) these metrics could be very interesting tools to use, as the shape of the study area can be taken into account better on a smaller scale.

Figure 2.7: Comparison of mathematically compact and spatially compact configurations of urban expansion



Mathematically compact Spatially compact

2.3.3 Metrics to be used in this study

Although not all metrics that are potentially interesting for this study can be used due to constraints in the data characteristics, there are plenty of metrics that are very well suited to be used in this study. Metrics on patch frequency and patch area seem to suit the research very well as they can give insight in amount of new housing areas and the size of these areas. These metrics include the "Number of Patches", "Largest Patch Index", "Distribution of Patch Sizes" and the "Urbanisation Degree" (Gustafson, 1998; McGarigal et al., 2009; Ritsema van Eck & Koomen, 2008; Seto & Fragkias, 2005). A simple measure on shape such as the "Perimeter-Area Ratio" or the very similar "Edge Density" (Gustafson, 1998; McGarigal et al., 2009; Ritsema van Eck & Koomen, 2008; Seto & Fragkias, 2005) might give additional insight in distribution of the area and shape of the patches and a variation of these metrics will therefore be used in this study.

Inspired by the metrics described in literature, six metrics were chosen and defined. These metrics will be used to test the hypotheses derived from literature. These six metrics have been inspired by literature but they have been slightly adjusted to suit the needs of this study even better. The most important adjustment made to the metrics is that they are all indexed. This means that the average of all municipalities is always 100 and that values under 100 indicate an underrepresentation and values over 100 represent an overrepresentation. Because of the fact that this study compares groups of municipalities, these indexed values can be averaged to an index value per group.

2.3.3.1 Un-weighted Patch Frequency Index (UPFI):
The UPFI is based on the metric "number of patches" (Gustafson, 1998; McGarigal et al., 2009; Seto & Fragkias, 2005) and describes whether the number of new patches in a municipality is above or below the national average. It is unrelated to the size or shape of the municipality. A value over 100 represents an overrepresentation of new patches in the municipality or group of municipalities.
*The UPFI is calculated as: (number of patches / (total number of patches / number of municipalities)) * 100*

2.3.3.2 Area Weighted Patch Frequency Index (AWPFI):
This variation on the AWPFI gives an indication of the relative amount of new patches per unit of area. It is closely related to the metric "Density of patches" as described in literature (Gustafson, 1998; McGarigal et al., 2009). The difference is that this metric is indexed so it can easily be compared between groups of municipalities. If the new residential area were homogeneously spread over the surface of all municipalities, all values would be 100. A value above 100 indicates an overrepresentation of new patches per unit of area for the municipality or group of municipalities.
*The AWPFI is calculated as: (number of patches within municipality /total area of the municipality in square meters) / (total number of patches / total area in square meters) * 100*

2.3.3.3 Residential Area Weighted Patch Frequency Index (RAWPFI):
The RAWPFI is very similar to the AWPFI, but instead of taking the total area into account it only takes residential area into account. It thus represents the amount of new cells per unit of residential area. This metric gives an insight in the relation between existing residential area and the new patches of residential area. If the value is over 100 there are relatively many new patches compared to the average number of patches per residential area. The RAWPFI is related to the "Urbanisation Degree" as described in literature (Ritsema van Eck & Koomen, 2008) as it represents the growth of residential area, taking the existing residential area into account.
*The RAWPFI is calculated as: (number of patches within municipality / residential area of the municipality in 1993 in square meters) / (total number of patches / total residential area in 1993 in square meters) * 100*

2.3.3.4 Indexed Largest Patch Index (ILPI)
The ILPI is an indexed version of the Largest Patch Index as described in McGarigal et al. 2009. The original Largest Patch Index gives the percentage of the area of a municipality that is covered by the largest patch in the same municipality. For the sake of comparison this adjusted instance of the Largest Patch Index sets the average of all municipalities to 100 so that the groups of municipalities can be compared with more ease.
*The ILPI is calculated as: ((largest patch size within the municipality in square meters/ the area in square meters of the municipality) * 100) / ((by the largest patch size in square meters in all municipalities / the area in square meters of all municipalities) * 100) * 100*

2.3.3.5 Patch Size Distribution Index (PSDI):
The PSDI is derived from the "Patch Size Distribution" as described in literature (Ritsema van Eck & Koomen, 2008). The larger the number is, the more the sizes of patches vary.
*The PSDI is calculated as: (standard deviation of patch sizes in square meters within the municipality / average standard deviation of patch size in square meters in all municipalities) * 100*

2.3.3.6 Area-Perimeter Ratio Index (APRI):

The APRI gives an indication of the shape of patches by comparing the area of patches by the length of their perimeter. The higher the number, the larger and / or more compact a patch is. The "Perimeter-Area Ratio" and the "Edge Density" as described in literature (Gustafson, 1998; McGarigal et al., 2009; Ritsema van Eck & Koomen, 2008; Seto & Fragkias, 2005) inspire the APRI, but because groups of municipalities are being compared the outcomes have been indexed for the sake of comparison ease.

*The APRI is calculated as: (area in square meters within the municipality / perimeter in meters within the municipality) / (area in square meters for all municipalities / perimeter in meters for all municipalities) * 100*

2.4 Research Hypotheses

This section translates the findings from the literature into expectations for selected groups of municipalities with regard to selected metrics. These expectations are used as hypotheses to be assessed in the statistical part of this research.

2.4.1 Expectations based on literature

Based on this literature review, expectations have been formulated regarding the values for different metrics for each group of municipalities with a specific policy. As a basis all values for municipalities that do not have a specific policy have been set to 0. The values for the other groups can be much higher (++), higher (+), equal to (0) lower (-) or much lower (--) than the values for municipalities with no specific policy. An overview regarding the expected outcomes of the metrics is provided in Table 2.1. The expectations will be briefly explained for each group of municipalities.

Table 2.1: Expected outcomes on metric values for the different groups of municipalities

Metric	**NORM[1]**	**GC[2]**	**VINEX[3]**	**NL[4]**	**NEN[5]**
Un-weighted Patch Frequency Index	0	++	+	-	--
Area Weighted Patch Frequency Index	0	+	+	-	--
Residential Area Weighted Patch Frequency Index	0	+	-	0	0
Indexed Largest Patch Index	0	+	++	-	--
Patch Size Distribution Index	0	+	+	-	--
Area-Perimeter Ratio Index	0	+	++	-	--

[1] Municipalities with no specific policy
[2] Municipalities with Growth-Pole policy
[3] Municipalities with VINEX policy
[4] Municipalities with National Landscape policy
[5] Municipalities with National Ecological Network policy

--	= Much less than municipalities with no specific policy
-	= Less than municipalities with no specific policy
0	= Equal to municipalities with no specific policy
+	= More than municipalities with no specific policy
++	= Much more than municipalities with no specific policy

2.4.1.1 Hypotheses for Growth-Pole municipalities

Due to the semi suburban composition of urbanisation in the Growth-Poles, these areas are expected to have a much higher number of patches than municipalities with no specific policy. This is expected to reflect in a high value for the Un-weighted Patch Frequency Index. Because the Growth-Pole municipalities are not necessarily very large, it is expected that their number of patches weighted by (total or residential) area is larger than for the municipalities with no specific policy, but not by much. Because the patches are not necessarily very large in the Growth-Pole municipalities, the Indexed Largest Patch Index is expected to be larger than for municipalities with no specific policy. The Patch Size

Distribution Index is expected to be roughly the same for all Growth-Pole municipalities, yet higher than for municipalities with no specific policy. The Area-Perimeter Ratio Index is expected to be lower for Growth-Pole municipalities as the patches of urban expansion are expected to be larger than in municipalities with no specific policy.

2.4.1.2 Hypotheses for VINEX municipalities

In VINEX municipalities, the amount of patches is expected to be bigger than in municipalities with no specific policy, but smaller than in Growth-Pole municipalities. The Un-weighted Patch Frequency Index and the Area Weighted Patch Frequency Index are expected to be higher than for municipalities with no specific policy. The expectation is that, compared to Growth-Poles, new housing areas in the VINEX municipalities are fewer in number and relatively larger in size. Therefore the largest patch index is expected to be much higher than for any other group of municipalities. As the VINEX policy aims at bundling urbanisation in the neighbourhood of larger cities, Residential Area Weighted Patch Frequency Index is expected to be lower than for municipalities with no specific policy. Because of the variation in the size of the VINEX projects, the Patch Size Distribution Index value is expected to be higher than for other groups of municipalities. The Area-Perimeter Ratio Index value is expected to be much higher than it is in municipalities with no specific policy as VINEX locations are characterized by large-scale housing developments and hence a lot of area per perimeter.

2.4.1.3 Hypotheses for National Landscape municipalities

For municipalities with National Landscape policy the Un-Weighted Patch Frequency Index, the Area Weighted Patch Frequency Index and the Indexed Largest Patch Index are expected to be lower than for municipalities with no specific policy. In these municipalities the urbanisation slogan is “Building for natural growth” and thus minimal urban development in small patches is what might be expected. The Residential Area Weighted Patch Frequency Index is expected to have more or less the same value as for the municipalities that have no specific policy because the amount of new patches is expected to be low and Natural Landscapes are characterized by their “green” environment. Among the municipalities with National Landscape status Patch Size Distribution Index values are expected to be lower than normal. Area-Perimeter Ratio Index values are expected to be smaller than for municipalities with no specific policy as the patches are expected to be very small.

2.4.1.4 Hypotheses for National Ecological Network municipalities

In municipalities covered by National Ecological Networks, very little change is foreseen. The Un-weighted Patch Frequency Index, the Area Weighted Patch Frequency Index, the Indexed Largest Patch Index and the Patch Size Distribution Index within this group are expected to show much lower values than for any other group of municipalities. For the same reason as with the National Landscapes, the Residential Area Weighted Patch Frequency Index is expected to be at the same level as for municipalities with no specific policy. Area-Perimeter Ratio Index values are expected to be much lower for this group of municipalities. If there is any urban development in these municipalities, it is expected to come in single patches.

3 RESEARCH METHODOLOGY

In this chapter the step will be made from research hypotheses derived from literature to numbers, which will be used to evaluate these hypotheses in the research results chapter (chapter 4). Data are a very important ingredient for the calculation. They act as a fuel for the computational model and like cars cannot run well on bad fuel the model cannot perform well on bad data. The data to be used have been carefully selected based on the needs for the analysis in this research. In the first section of this chapter, the choices made while selecting the data for this research will be discussed and the reader will be familiarised with the datasets that are used. After discussing the data, the focus of the chapter will move to the actual calculation of the metrics. While building the model for the calculation, considerations of scale and sensitivity and practical choices play a very important role. In the second part of this chapter, these considerations and practical matters will be thoroughly discussed.

3.1 Research Data

The data demands for this research are rather limited when measured in number of datasets. However, as this research is comparing datasets for several years the consistency and quality of data are of utmost importance. Basically, only three datasets are needed for this study: a municipality dataset and two land use datasets: the old and new situation. However, also datasets regarding the policies are needed for determining for each of the municipalities what policy applies to it. In the following section all the datasets will be briefly discussed.

3.1.1 Land use datasets

The land use dataset plays a key role in this research. In the start up phase of this research the suitability for this research project has been evaluated for a number of datasets:

- HGN ("Historisch Landgebruik van Nederland" or Historical Land Use of the Netherlands): a 25x25 meters raster on land use, which contains a class on built up area but not a class on housing.
- LGN version 3+, 4 and 5 ("Landelijk Grondgebruik Nederland" or Land Use Database of the Netherlands): 25x25 meters thematic rasters of land use, contain (like HGN) only a class for built up areas and not a separate class for housing.
- TOP25 (1:25,000 topographic map of the Netherlands) scans for different years: these datasets need a lot of pre-processing before they might be used for spatial analysis.
- BBG Raster ("Bestand Bodemgebruik" or Land Use Dataset): CBS land use map available in raster format, available for the years 1993 and 1996.
- BBG Vector ("Bestand Bodemgebruik" or Land Use Dataset): CBS land use map available for the years 1993, 1996, 2000 and 2003.
- TOP10 Vector (1:10,000 topographic dataset of the Netherlands): available for the years 2003, 2004, 2005 and 2006 but the acquisition date differs for different parts of the dataset).
- TOP10 Classic (old 1:10,000 topographic dataset of the Netherlands digitised per map sheet): from 1993 to 2000, visual inspection shows that the quality is rather poor. The problem is that it has been digitised in map sheets, which do not perfectly fit together.

From the above datasets the BBG Vector datasets from 1993 and 2003 (Figure 3.1) have been chosen for the following reasons:

- they contains a class for housing in both years,
- they represent the situation as it was in the year they describe,
- they cover a wide enough range of years for this study,
- the spatial scale of the datasets is appropriate for this research.

However, there are a few drawbacks to these dataset:

- classification has changed over years,
- the spatial scale varies over years (from 2000 on the dataset has been linked to the features in TOP10 vector).

The first drawback seemed to be not as much a challenge as it could potentially be: both datasets have a class of housing (although the class numbers differ). The second drawback turned out to be a far greater challenge, which has had a major influence on the approach to the spatial analysis. Because the datasets for the two years are not based on the same geometry, sliver polygons with false differences occur when comparing the datasets for the two different years. The Geodesk of Wageningen University provided the land use datasets.

Figure 3.1: Sample image of the land use dataset of 2003 (BBG2003)

For the sake of reproducibility, hardly any pre-processing has been performed on the land use datasets. Most operations that could be considered pre-processing have been written into the analysis script and are thus performed during the spatial analysis. Although this is more time-consuming during analysis runs, it provides a better insight into the operations performed to the datasets. The only operation that has been performed prior to the analysis is to reclassify the values of the land use classes: the housing class has been given a distinctive class (value = 99) and other classes have been truncated to main classes (in the case of 2003: class 33, mining, has been truncated to class 3, semi-built up area). However, this truncation is not a must for the analysis.

3.1.2 Municipality dataset

After the choice of the land use datasets, the decision on the municipality map to use didn't impose much of a challenge. The municipality map of the last year of analysis (2003) was chosen as the dataset to use (Figure 3.2). The reason to use the last year is that several municipal have merged during the time span that is studied, and it is more convenient to merge data for municipalities than to split them. The municipality map of 2003 contains 489 different municipalities and was provided by the Utrecht University, Faculty of Geosciences.

Figure 3.2: Sample image of the municipality map of 2003

The municipality dataset is extended with thematic data on the different policies. Therefore data on the restrictive policy (con-new residential land use) and allocation policy (pro-new residential land use)is required.

3.1.3 Datasets for the allocation policies

Determining what municipalities are subject to the Growth-Pole policy and to the VINEX policy, requires datasets on these policies. Hereafter, the data on the allocation policies will be briefly described.

3.1.3.1 Growth-Poles

Information on the Growth-Pole municipalities has been gathered from two sources. A report from the Social and Cultural Planning bureau features a list with Growth-Pole municipalities (containing 16 municipalities) (Bruijne & Knol, 2001) and there also is a list on Wikipedia's Growth-Pole page (containing 17 municipalities) ((Wikipedia contributors, 2009a)). Both lists have been compared and the list on Wikipedia features one municipality that is not featured in the list from the Social and Cultural Planning bureau, namely Etten-Leur. The list of Growth-Pole municipalities consists of the municipalities that are doubly confirmed as Growth-Pole municipalities by both sources. The complete list of Growth-Pole municipalities is featured in Appendix C.

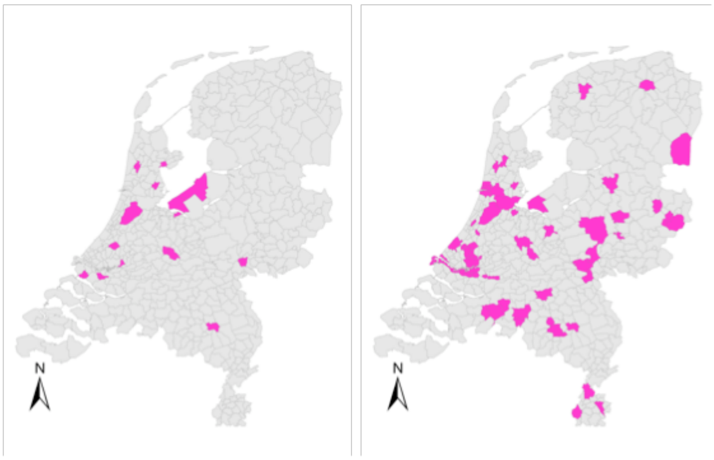
3.1.3.2 VINEX

As the VINEX policy document does not provide a list of municipalities that eventually got a VINEX location, alternate sources had to be consulted for an overview of the municipalities' VINEX locations (Wikipedia contributors, 2009b). Wikipedia has a list of the largest VINEX locations, however this list is incomplete. The Research Institute for Public Health and Environment (RIVM) published a research report containing a list of the VINEX municipalities and the building plans for each VINEX location in 2006 (Lörzing et al., 2006). The ministry of Housing, Spatial Planning and the Environment (VROM), which is responsible for the spatial planning policy, does not provide a list of VINEX locations but refers (Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer, 2010) to a list on another website managed by a private company (http://www.vinex-locaties.nl/ (BIJN, 2009)). This website is clearly ad-funded, the list seems very outdated and no reference to a source is to be found. Because of the doubts on the trustworthiness of this list, it was decided to choose another list as the basis for the analysis: the one from the report by the Research Institute for Public Health and Environment. A complete list with VINEX locations that were listed by the three above sources can be found in Appendix D.

3.1.3.3 Growth-Pole and VINEX

On the basis of the lists of Growth-Pole and VINEX municipalities, maps of the Growth-Pole and VINEX municipalities were produced (Figure 3.3). Some municipalities appear on both maps: they were subject to both that Growth-Pole and the VINEX policy.

Figure 3.3: Growth-Pole (left) and VINEX (right) municipalities



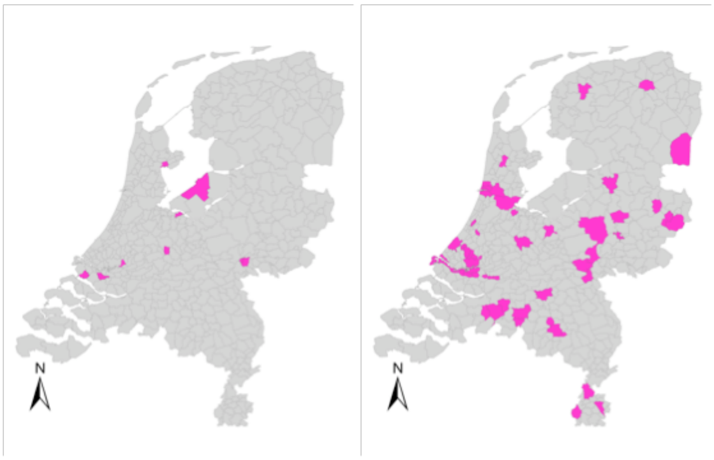
Because the Growth-Pole and VINEX policy do not temporally overlap, it is possible that a municipality has been subject to both the Growth-Pole and the VINEX policy. Because no hypotheses for this group of municipalities have been formulated, these municipalities will be excluded from the general evaluation of the research expectations. However, they will be displayed as a separate category when analysing the results.

The seven municipalities that are subject to both the Growth-Pole and the VINEX policy are: Alkmaar, Almere, Haarlemmermeer, Helmond, Houten, Purmerend and Zoetermeer (Figure 3.4).

Figure 3.4: Municipalities that are subject to both Growth-Pole and VINEX policy

The municipalities that are Subject to both the Growth-Pole policy and the VINEX policy are removed from the selections for the individual policies. The municipalities that remain selected as Growth-Pole or VINEX municipality are displayed in Figure 3.5.

Figure 3.5:Municipalities that are subject to the Growth-Pole policy and not the VINEX policy (left) and municipalities that are subject to the VINEX policy and not the Growth-Pole policy (right)



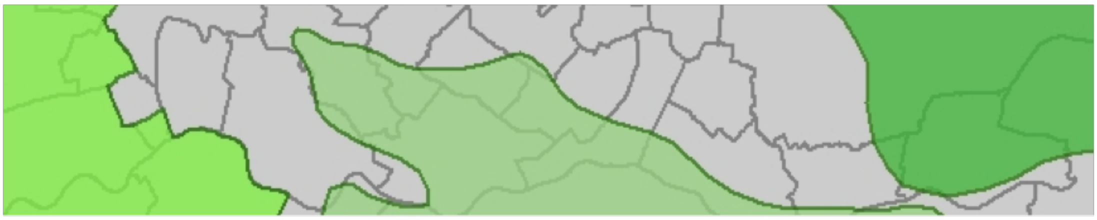
3.1.4 Datasets for the restrictive policies

To determine what percentage of either of the municipalities is covered by the restrictive policies, datasets with polygons of the restriction policies are overlaid with the municipality map. The datasets containing the restrictive policies represent the situation as it was in 2004, the first year after the temporal scale of this research. As a long time passes before a preserved area is adopted in the national policy, it is assumed that the policy as it is in 2004 gives a good representation of the preserved areas during the time span of this research.

3.1.4.1 National Landscapes

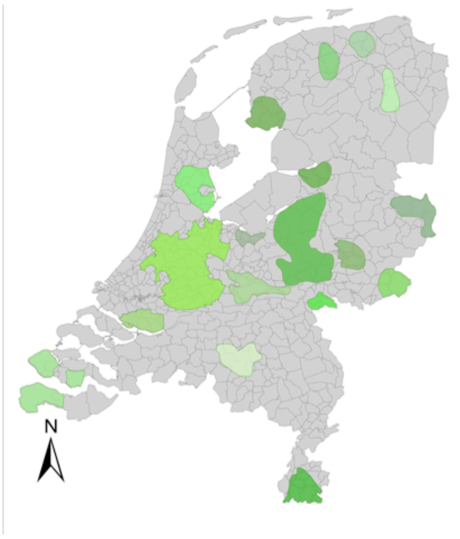
The ministry of Housing, Spatial Planning and the Environment (VROM, responsible for the maintenance of this dataset), has provided the dataset of the National Landscapes in 2004 (Figure 3.6).

Figure 3.6: Sample image of the National Landscapes 2004 dataset



As the sample of the dataset shows, the borders of most National Landscapes are rather smooth. This is because at that time no definite decision had been made regarding the exact borders of the National Landscapes. The only National Landscape that had a border that was agreed upon in 2004 is the Green Heart (left on the sample image). An overview of all National Landscapes is displayed in Figure 3.7.

Figure 3.7: Overview if the National Landscapes in 2004



3.1.4.2 National Ecological Networks

The Geodesk of Wageningen University has provided the dataset of the National Ecological Network in 2004 (Figure 3.8). It contains the National Ecological Network as it formally was in 2004 (netto EHS) of the national parks, the Natura 2000 area and the connection zones.

Figure 3.8: Sample image of the National Ecological Network 2004 dataset

The borders for the National Ecological Network are far more detailed than they are for the National Landscapes. The total National Ecological Network for 2004 is displayed in Figure 3.9.

Figure 3.9: Overview of the National Ecological Network in 2004

3.1.5 Combining the municipality data with the policy data

Using the data on municipal inclusion/exclusion for allocation and restrictive policies, thematic data were added to the municipality dataset. A number of attribute additions have been made to the municipality dataset in order to allow for comparison of groups of municipalities after running the spatial analysis:

- GC: value is 1 if the municipality is subject to the Growth-Pole policy, else 0;
- VINEX: value is 1 if the municipality is subject to the VINEX policy, else 0;
- GC_VINEX: value is 1 if the municipality is subject to both the Growth-Pole policy and the VINEX policy, else 0;
- NATLAND: value is 1 if the municipality is subject to the national landscape policy, else 0;
- NEN: value is 1 if the municipality is subject to the national ecological network policy, else 0.

It is clear whether a municipality is subject to the Growth-Pole and VINEX policy or not. In these policies municipalities have been chosen to be subject to the policy or not. With national landscapes and national ecological networks this is different, as nature does not take administrative boundaries into account. For these municipalities a decision rule had to be developed, using the percentage of the municipal area that is subject to the policy. This decision rule is used for the grouping to aid the general comparison; for in depth analysis another method is used.

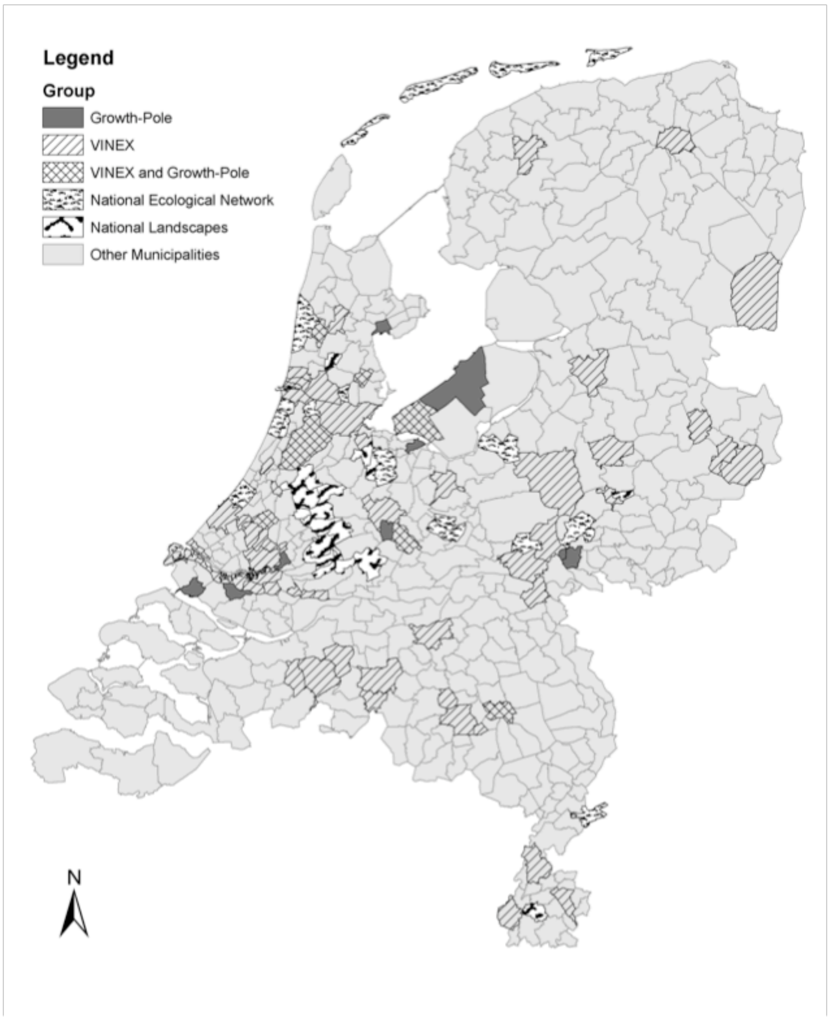
The following rules have been used:

- A municipality is considered to be subject to the national landscape policy if the municipality is one of the 18 municipalities with the largest portion of the municipal area covered by national landscapes.
- A municipality is considered to be subject to the national ecological network policy if the municipality is one of the 18 municipalities with the largest portion of the municipal area covered by the national ecological network.

The choice to use the 18 municipalities with the largest portion of the territory under restrictive policy is both practical and for comparison reasons. The 18 first municipalities for both groups can be assigned without conflicts; thereafter municipalities have high values for both the percentage of area covered by National Landscapes and the percentage of area covered by the National Ecological Network. Besides this practical matter, 18 municipalities is a group size that is within the range of the sizes of the groups with allocation policies: 9 municipalities are Growth-Poles and 45 are VINEX municipalities. An overview of all groups based on policy is displayed in Figure 3.10.

For further analysis regarding the restrictive policies, the relation between the metrics and the restrictive policies will be evaluated for all municipalities. Therefore there will be no Boolean map with one group of municipalities with restrictive policies and another group without, but all municipalities will get a value for the percentage of the total municipality area that is covered by the restrictive policy. These are two variables, one for the National Landscapes and one for the National Ecological Network. As the values for these variables are measured at the ratio measurement scale and the metrics at the interval measurement scale, there will be additional possibilities in the analysis when not converting the restrictive policies to Boolean values.

Figure 3.10: Groups of municipalities based on policy in the Netherlands



3.2 Calculating land use change

New residential areas are identified by comparing the datasets for 1993 and 2003. A parcel of land with non-residential land use in 1993 and residential land use in 2003, is identified as new residential area. Because the study area consists of all municipalities in the Netherlands (according to administrative boundaries in 2003), most operations have to be performed 489 times (for each municipality in 2003). Scripting offers a solution to perform the repetitive tasks more conveniently, as it enables the user to create loops that recursively perform a certain operation. While scripting can take more time initially, it can pay off when operations have to be repeated. By using custom functions that recursively perform certain tasks, the script makes it easy to make minor adjustments and recalculate the patch statistics. In this research project, Python has been selected as scripting language. Python offers a full functional programming environment that is platform independent. ESRI has recently adopted Python as the main scripting language for ArcGIS. A Python script using ESRI's Geoprocessing object has been used for calculating the patch statistics for new residential areas.

Besides the technical challenge of calculating the metrics there are also methodological considerations. The choice of a suitable cell size and the analysis of sensitivity of the results to cell size are of key importance in this research. At first, a prototype (fast draft) script was evaluated. Second, lessons learned from the prototype script were used to write and evaluate the final script for this research.

The following sections will elaborate on the calculation of metrics of land use change for this research, and methodological considerations that play an important role in this process. Firstly, some considerations regarding cell size are discussed. Secondly, the prototype script will be explained. It served as a base for refinements and for generating data for initial analysis of cell size sensitivity. Thirdly, an initial analysis of cell size sensitivity was conducted. This initial analysis provides a rough indication of a suitable range of cell sizes for this particular research project. Furthermore this analysis can identify areas of refinement for the model to be used to calculate the land use metrics. Fourthly, the refined model will be discussed. Finally, we shall discuss the analysis of cell size sensitivity using a number of results with different cell sizes for the adjusted model.

3.2.1 Cell Size

Previous research has shown that (spatial) scale considerations should not be underestimated in land use modelling (Agarwal et al., 2002; Heistermann et al., 2006; Parker, Hessl, & Davis, 2008; Schrojenstein Lantman, 2008). Different phenomena of land use modelling operate at varying spatial scales. Therefore, measures designed to capture the effect of these phenomena are sensitive to scale. It is expected that a curve of effectiveness can be identified when using land use metrics over a range of spatial scales. This means that the metrics are expected to perform better on certain spatial scales than on other spatial scales.

While making a grid of the study area there are several considerations to be taken into account. The first constraint is the resolution of the source data. Theoretically, a point in space has no exact location as its location can be calculated to infinite precision. However, every existing digital land use dataset has once been digitized at a given scale. For example, the land use dataset representing the situation in the Netherlands in 2003 has been derived from the 1:10,000 topographic map of the Netherlands. Therefore, although digital vector maps can seem scale-less to the user, it makes no sense to use the dataset on a resolution higher than 1:10,000 as the dataset was not created for such high-scale analysis. The map representing land use in 1993 has a slightly lower resolution than the 2003 map. Therefore it will be assumed that the source data is usable on a scale of 1:25,000 or smaller. When viewing the data on a 1:25,000 scale, for example, a 25x25 meter grid cell will be 1 by 1 millimetre.

Secondly, the phenomenon to be studied imposes constraints on the resolution of the research data. When studying elevation for example, changes can vary from very smooth to very abrupt. In that case the changes within each meter can be very interesting and thus a very small cell size is desirable. However, new housing areas are usually larger than 1x1 meter as one parcel in a medium density housing area can be for example 25x25 meters. Therefore a new housing area containing several houses could easily be identified on a 100x100 meters scale.

Thirdly, the metric used to quantify a spatial pattern can be more or less sensitive to spatial scale. If for example circularity ratio is used, a metric that measures to what extent a patch deviates from its most compact form (a circle), one can imagine that a high resolution that preserves the patch shapes is desired (Ritsema van Eck & Koomen, 2008). On the other hand, when a metric less sensitive to shape is used, like patch size, a lower resolution can provide satisfactory results.

Fourthly, digital maps are de facto a simplified representation of what we call the ‘real world’. When we are mapping the world around us we have to make decisions concerning classification of ‘real world’ phenomena and where to draw certain boundaries. In addition plain errors such as digitising mistakes occur. Especially when comparing different maps these interpretations and errors have a large effect on the analysis, generating noise. The choice of a larger spatial resolution can help to reduce noise caused by cartographic decisions and mapping errors.

Finaly, there is a classical trade-off between cell size and computational capabilities. In a grid with square cells, when the dimensions of the cells are divided by x, the number of cells increases by the square of x. A 10x10 meter grid will for example contain 100 times as many grid cells as a 100x100 meter grid. Although large grids can be demanding on computer memory, processing challenges decrease as Moore's law (a doubling of the number of transistors on a processor every two years) does still apply to computer technology development.

3.2.2 Prototype procedure for calculating metrics of land use change

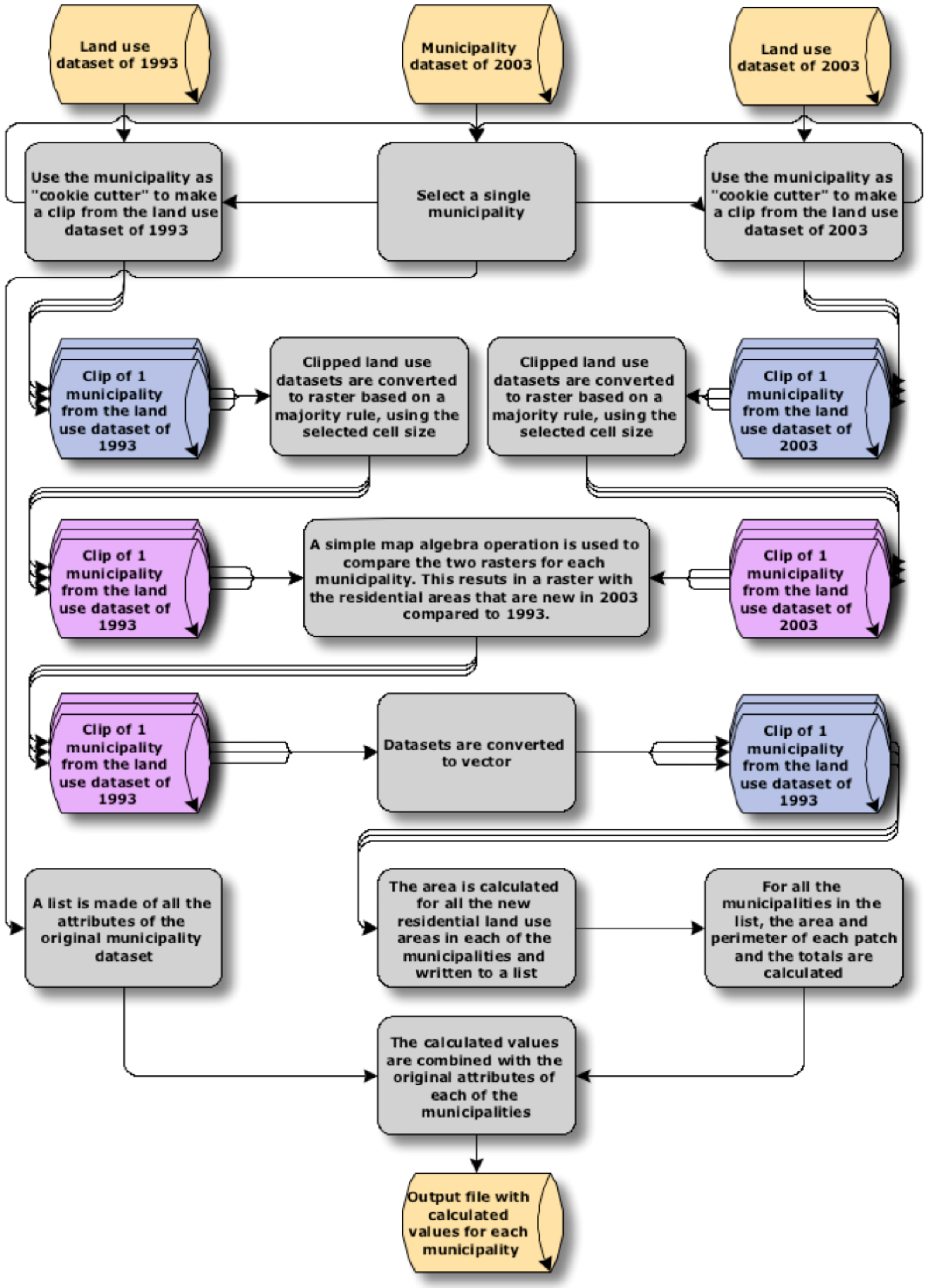
The following section will describe the processes in the prototype Python script step by step. A visual representation of the script steps can be found in Figure 3.11, the script itself can be found in Appendix E.

The script starts off by selecting a municipality from the vector dataset containing all municipalities in 2003. The selected municipality is used as a cookie cutter to clip areas from the land use datasets of 1993 and 2003. When this is done for a municipality, the next municipality is selected and the process is repeated.

When all municipalities have been clipped from both land use maps, the clipped land use datasets are recursively converted to raster using the preselected cell size. The method that is used to convert the datasets to raster is the "Maximum Combined Area", so that the land use that has the largest area in the cell determines the cell value. This method has an advantage over the "Cell Center" method (default in ArcGIS): small features that could increase noise in the analysis like small streamlets and ditches tend to get filtered out of the raster dataset. The switch to raster environment is made to prevent potential issues that could occur in a vector environment, such as the occurrence of numerous sliver polygons due to slightly different borders of features in the two land use datasets.

Using a conditional function in Map Algebra the raster datasets for both years are compared to each other. Cells that have residential land use in 2003 and another land use in 1993 are selected. After the map algebra operation the resulting raster datasets are converted to vector again. Vector datasets have the advantage that additional fields can be added more flexibly and calculated in the attribute table. The resulting vector datasets have exactly the same geometries as the raster datasets they are derived from. For the vector datasets containing the differences in housing areas for the two years, the area of each patch is calculated in the attribute table. Next, Python reads the area values from the attribute table of the vector dataset containing the differences in each municipality and adds them to a list in the computer memory. For each municipality the number of patches, sum of patch area, the mean patch area and the standard deviation are calculated into a second list. A third list is created that contains all attributes of the original clips. Finally, the second list containing the statistics and the third list containing the original attributes are combined into a final list. This list is then written to a file that can be opened using a spreadsheet or statistical software package.

Figure 3.11: Schematic representation of the prototype calculation procedure script



3.2.3 Test of scale sensitivity for the prototype calculation procedure

Identifying the effect of spatial scale while analysing expansion of residential land use in the Netherlands required a test on a sample subset of the research data. The effects of scale on the results (like cells representing sliver polygons) are expected to occur in every municipality, independent of the size or shape of the municipality. Therefore a random selection was made from the entire population without defining sub-groups. From the 489 municipalities that the Netherlands contained in 2003, 10 were randomly selected as a test dataset. A Python script was used to randomly draw 10 numbers from a list with numbers 1-489 (Figure 3.12). The municipalities with the feature id's (unique identifier number) that are the same as the drawn numbers are selected as a test dataset. The municipalities belonging to these numbers are summarized in Table 3.1.

Figure 3.12: Script for random selection (left) and result (right)

```
IDLE 1.1.1
>>> import random
>>> Population = []
>>> Number = 1
>>> while Number <= 489:
	Population.append(Number)
	Number = Number + 1


>>> Sample = random.sample(Population, 10)
>>> Sample.sort()
>>> for x in Sample:
	print x
```

```
55
97
248
302
356
364
396
456
466
473
>>>
```

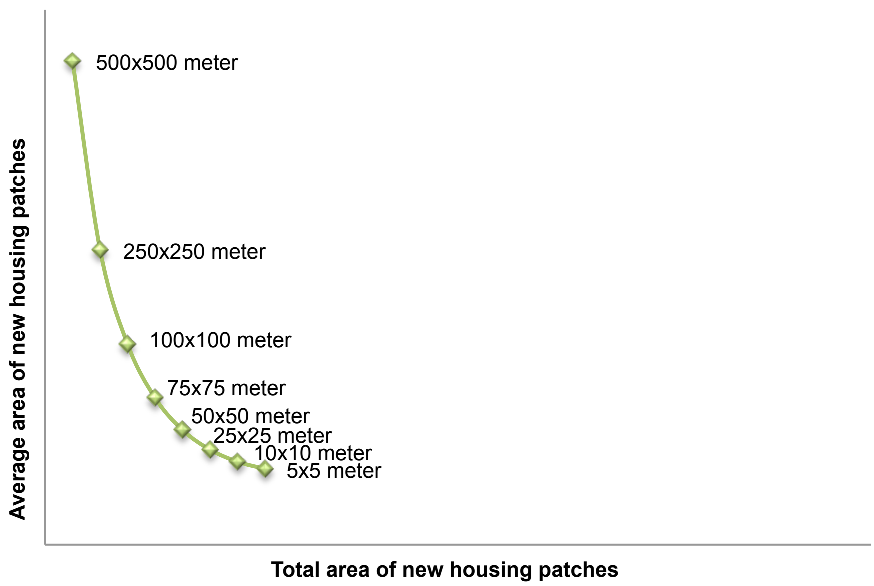
Table 3.1: Randomly selected municipalities for tests of scale sensitivity

Number / FID	CBS Code	Municipality name
55	376	Blaricum
97	150	Deventer
248	25	Marum
302	431	Oostzaan
356	1702	Sint Anthonis
364	91	Sneek
396	619	Valkenburg ZH
456	683	Wymbritseradriel
466	1666	Zevenhuizen-Moerkapelle
473	1896	Zwartewaterland

For the selected municipalities the new housing areas were subtracted comparing the land use dataset of 1993 with the land use dataset of 2003. This analysis was run using eight different cell sizes: 5x5 meter, 10x10 meter, 25x25 meter, 50x50 meter, 75x75 meter, 100x100 meter, 250x250 meter and 500x500 meter. For the selected municipalities three metrics were calculated: the number of new housing patches, the absolute area of new housing patches and the average area of new housing patches.

Prior to the analysis the expectation was that with increasing cell sizes the average size of the patches would increase and the total area of new housing patches would decrease due to the elimination of noise (errors, like small patches due to minor differences in the road network through urban areas classifying cells as road in 1993 and as housing in 2003). This expected effect is visualized with fictive data in Figure 3.13.

Figure 3.13: Expected effect of cell size on sample data (total area versus average area for each cell size)

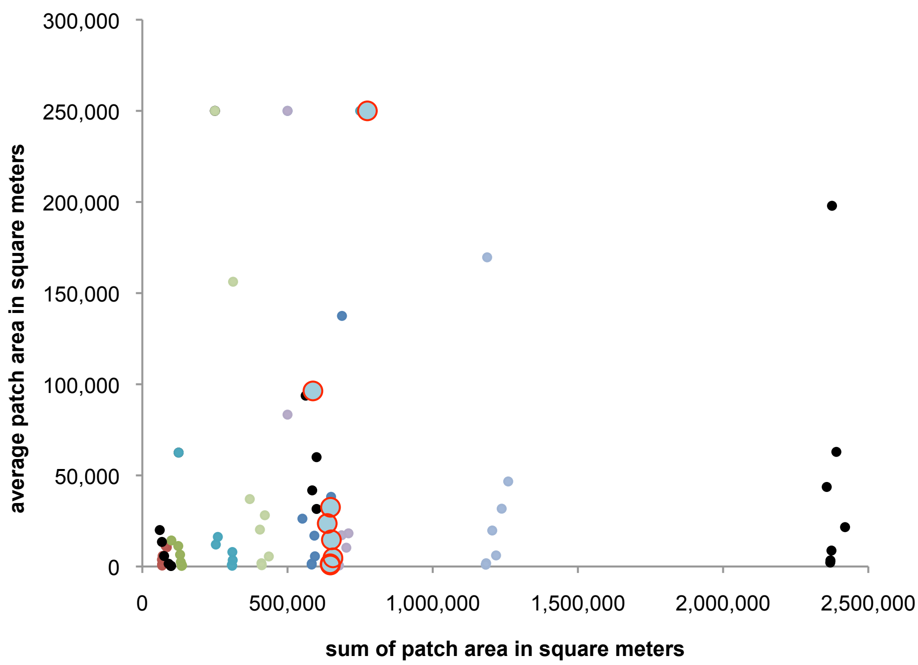


When plotting the results of the analysis with the sample dataset an unexpected pattern surfaced. As was expected the average area of patches increases with the cell size. However, the total area of the new housing patches is rather insensitive to cell size. Moreover, the total area of the new housing patches eventually increases with cell size until a certain threshold value is reached where the cells are too large to capture the new housing areas. When the threshold value is reached, the sum of the new housing patches decreases dramatically and goes to zero eventually.

When examining the three calculated metrics (number of new housing patches, the absolute area of new housing patches and the average area of new housing patches) individually, the stability of the sum of the changed area is confirmed. The number of patches averaged over the 10 sample municipalities falls while cell size increases (from about 680 with 5x5 meter cells to about 2 with 500x500 meter cells). The average patch size averaged for the 10 sample municipalities rises with the cell size (from about 825 m2 with 5x5 meter cells to about 250,000 m2 with 500x500 meter cells.

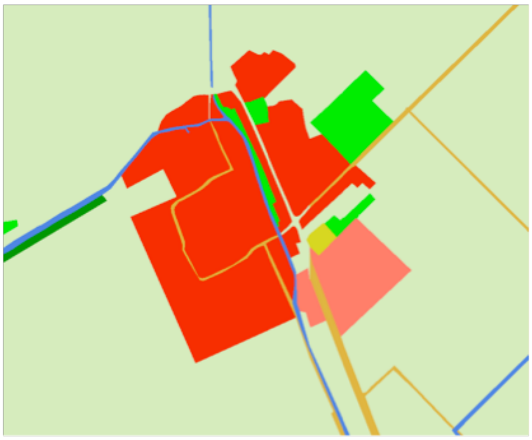
For two of the sample municipalities, no change was observed at a cell size over 100x100 meters. New housing areas of one hectare (100 by 100 meters) are interesting in the context of this research. At cell sizes of 250x250 meter and 500x500 meter, changes that could be observed at smaller cell sizes disappear for 2 out of the 10 municipalities. Therefore, cell sizes of 250x250 meter and 500x500 meter are considered to be too coarse for this study. On the other hand, values especially for number of patches and average area of patches with cell sizes of 5x5 and 10x10 meters deviate relatively much from the values obtained with cell sizes between 25x25 and 100x100 meters (this pattern is displayed in Figure 3.14). As the parcel of an individual house often is larger than 10 by 10 meters, these cell sizes are considered to be too fine for the purpose of this research. More graphs on the effect of cell size can be found in Appendix F.

Figure 3.14: Effect of cell size on the sample dataset (total area versus average area for each cell size)

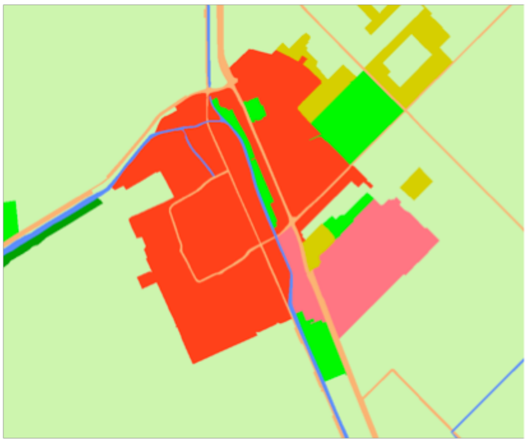


In order to judge the performance of 25x25 to 100x100 cell sizes, the changes on these cell sizes have been mapped for a small village in the centre of municipality #466, one of the sample municipalities (Figure 3.15). Visual inspection shows that on cell sizes of 25x25 and 50x50 meter there are more single cell changes that are likely to be noise than with cell sizes of 75x75 and 100x100 meters.

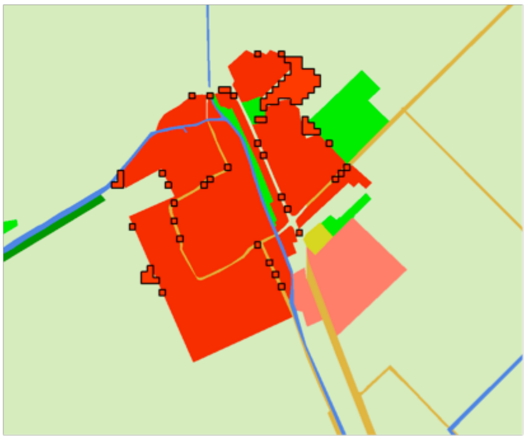
Figure 3.15: Municipality # 466, Small village in the centre: New residential land use in 2003 compared to 1993 (red cells with black border)



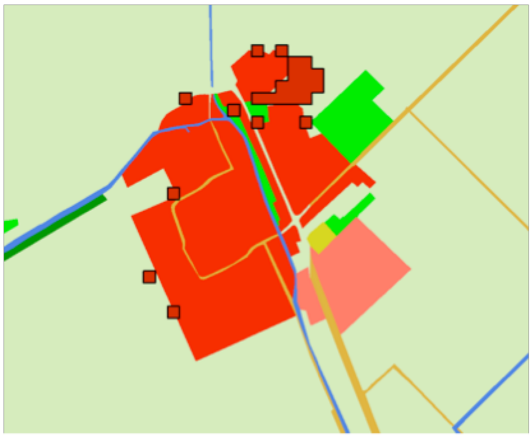
Land use 1993



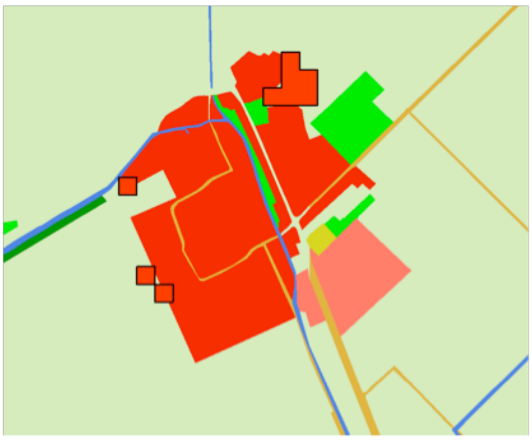
Land use 2003



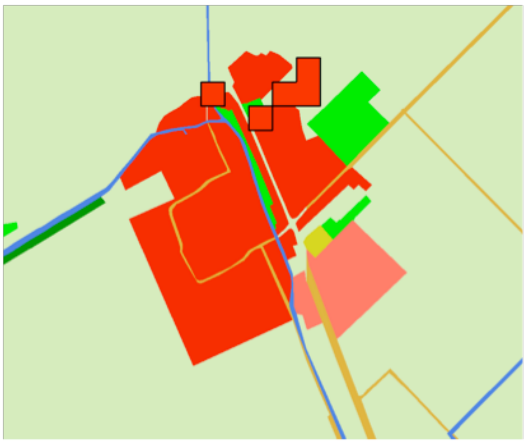
Changes with 25x25 meter cell size



Changes with 50x50 meter cell size



Changes with 75x75 meter cell size



Changes with 100x100 meter cell size

3.2.4 Refined procedure to calculate metrics of land use change

The results obtained by calculating the metrics of land use change have proven that it is very likely that better results can be obtained by refining the calculation method. Although not very obvious at larger cell sizes, there was a considerable amount of noise in the results from the initial method to calculate metrics of land use change, especially close to roads.

This observation led to the decision to alter the procedure to calculate metrics of land use change. The most important changes are:

- All raster datasets have the same origin, which is similar to the raster datasets that are used by the PBL in the Land Use Scanner (Figure 3.16). In the prototype procedure all municipalities had different origin coordinates.
- New cells of residential land use are identified on a 10x10 meter raster and later scaled up to the resolution of analysis. In the initial procedure the comparison was performed at the final cell size, preserving less detail while comparing.
- Municipality clips are made in a raster environment to ensure that all municipalities will in the end fit in the original extent like pieces of a puzzle. In the prototype operation, the municipalities were clapped based on the vector municipality map. This could cause the raster datasets of the municipalities not to fit together without overlap again.

Changing the procedure to calculate metrics of land use change implied that the first half of the script had to be rewritten. The final part of the script - reading the values from the files and calculating the statistics - could remain virtually unchanged. Because the second part of the script remained the same, the first part had to be written in such a way (definitely not the most efficient procedure) that it had the same output as the original script on the place where the two parts meet. A schematic representation of the refined script can be found in Figure 3.17, the script can be found in Appendix G.

The refined scripts starts off by converting the land use datasets from 1993 and 2003, and comparing them to find new residential developments. This process takes place on a 10x10 meter raster. The result of this comparison is a 10x10 meter Boolean raster representing patches of residential land use that are in the 2003 dataset but not in the 1993 dataset. Secondly the raster with new residential land use patches is scaled-up to the cell size of analysis based on a majority rule. Next the municipality map is converted to raster (using the cell size of analysis) and all municipalities are clipped from the resample change map using a recursive map algebra operation. After all the individual municipalities are clipped, the municipalities are converted to vector. These vector datasets are used as input for the second half of the original script, calculating the statistics and area, and writing the results to a file, which has been preserved. Because the clip operation on the municipalities is no longer performed in a vector operation, the original attributes can no longer be copied from the municipality clips. Therefore a workaround was written copying the attributes from the original municipalities dataset. The list of attributes is then joined to the list containing the patch values for the municipalities using the CBS code as common field.

Figure 3.16: Extents of the raster dataset in the adjusted calculation procedure.

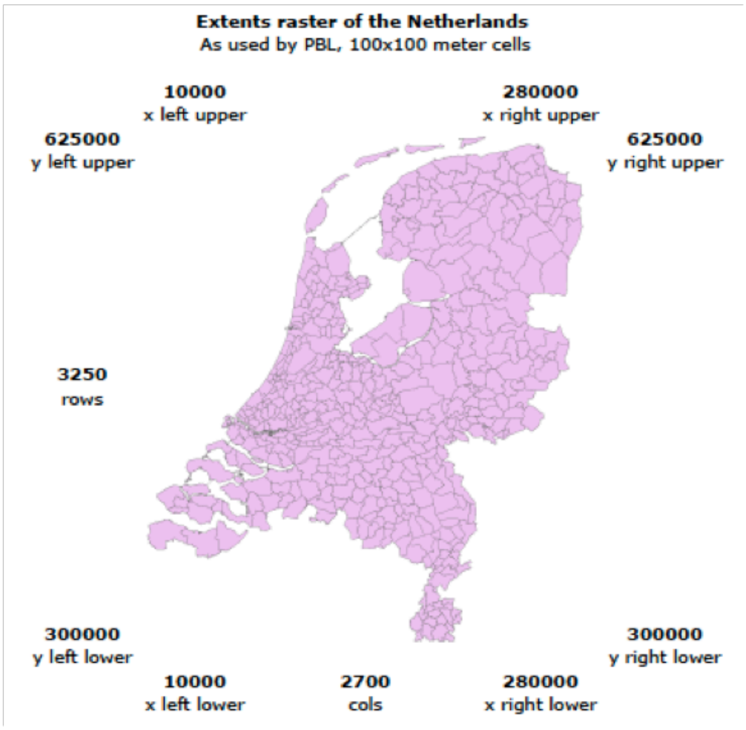
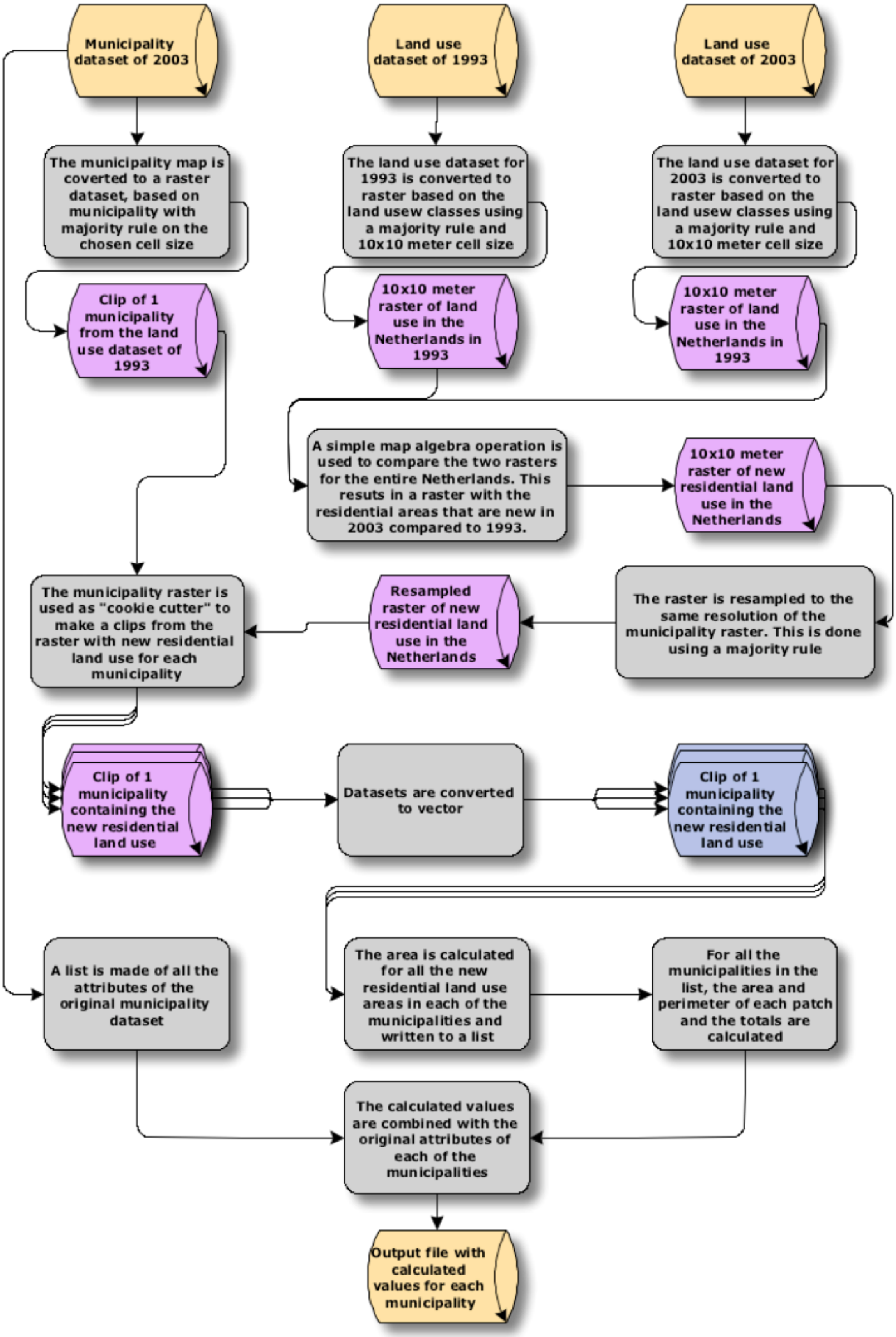


Figure 3.17: Schematic representation of the adjusted calculation procedure script



3.3 Assessments of scale sensitivity for the refined method of calculation

After redefining the procedure for calculating metrics of land use change, the sensitivity to spatial scale was recalculated. As the changes of urban area are now initially calculated on a 10x10 meter raster for every cell size of analysis, only values that are multiples of 10 could be used as cell sizes (and thus not 5x5, 25x25 or 75x75 meters as before). Because it is clear that cell sizes of 25 meters and lower and cell sizes over 100 meters are not suited for this analysis, the focus is on a smaller range of cell sizes now. The cell sizes to be analyzed are 40x40, 60x60, 80x80 and 100x100 meters.

Analyzing the values for the different cell sizes, the expected pattern of decreasing sum of area with an increasing average area is not clearly found. Looking at this aspect the pattern seems similar to the pattern found after the initial analysis (Figure 3.18). While visually inspecting the results for the different cell sizes in an example village in one of the sample municipalities it becomes clear that the new method of calculation greatly reduces the noise in the analysis. With a cell size of 40x40 meters, noise is clearly less than on a 50x50 meter cell size in the initial analysis (Figure 3.19). In Appendix H, additional graphs assessing the effect of cell size on the number and size of patches can be found.

The sum of changed area does not clearly respond to the cell size (Figure 3.20). The previous analysis of sensitivity to cell size has shown that a cell size between 50x50 and 100x100 meters is most suitable for the analysis of the results. Because in this analysis the raster extents of the Dutch decision making models are used and because there are no clear (positive or negative) effects on the results at one of the examined cell sizes, the cell size of the formal models (which is 100x100 meters) is adopted as well. By using the same cell size, the results of this study are easier to compare to input or results of other models.

Figure 3.18: Effect of cell size on the sample dataset with the adjusted calculation procedure (total area versus average area for each cell size)

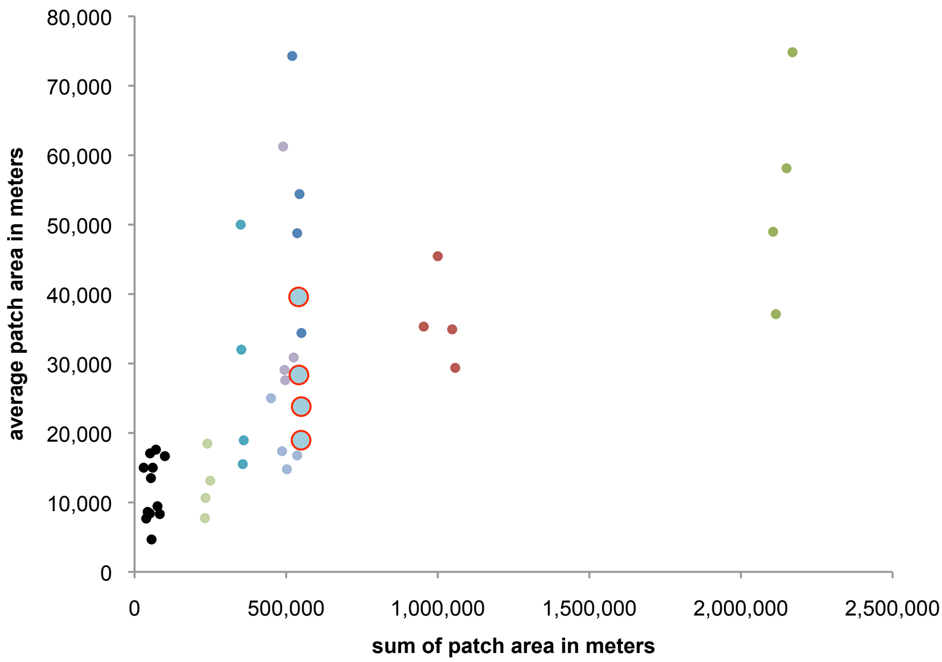


Figure 3.19: Municipality # 466, Small village in the centre of the municipality: New residential land use in 2003 compared to 1993 with adjusted calculation method (pink cells with black border)

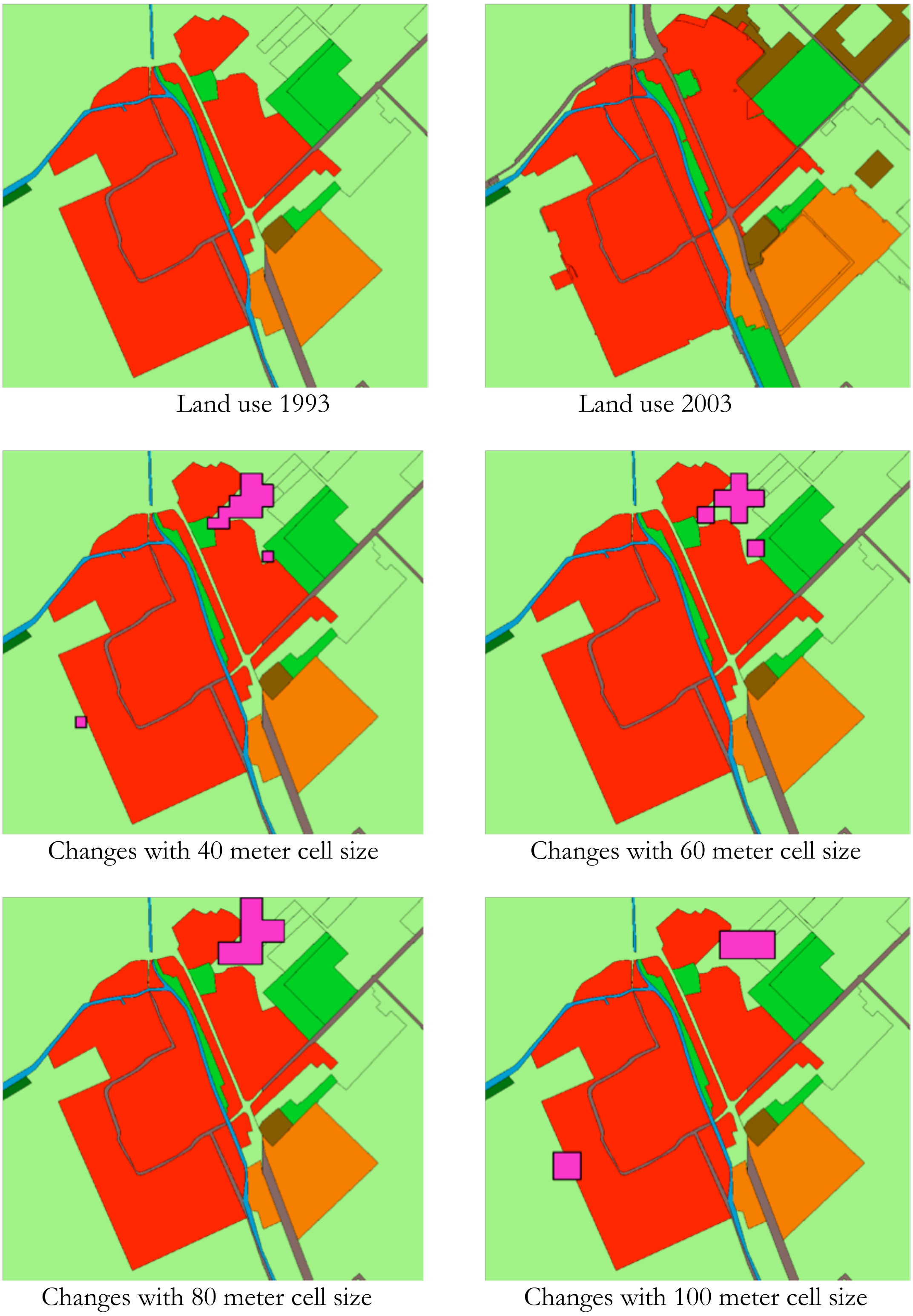
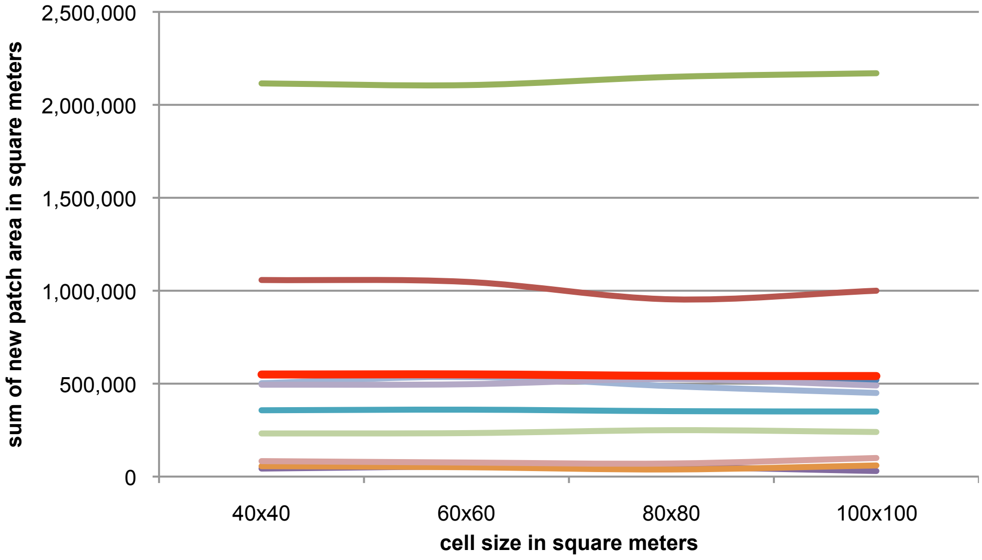


Figure 3.20: Adjusted calculation procedure: effect of cell size on the sum of changed area



4 RESEARCH RESULTS

This chapter will elaborate on the research results. The results will be analysed step by step. Firstly, this chapter will go back to the hypotheses formulated previously and check if the results meet the expectations based on the literature research. This aims to give a broad overview of the key findings of the empirical work. Secondly, we shall take a closer look at the behaviour of the outcomes of the previously formulated metrics. For gaining a better understanding of the way in which the metrics behave, the metrics and the distribution of their values will be analysed. Thirdly, the results for groups of municipalities with different policy goals will be analysed using the different metrics. Finally the chapter will wrap up with an overview of the most striking findings.

4.1 Overall patterns for the municipality groups

Before analysing the results in detail, we shall first look at key findings and sketch general profiles for the different groups of municipalities. After these general profiles have been formulated, this section revisits the research hypotheses and matches them with the calculated metric values.

In *Growth-Pole municipalities*, relatively many new residential land use developments have taken place. This is valid in absolute numbers as well as in relative terms, when weighted by the total residential area. The Growth-Pole municipalities distinguish themselves from the other groups by having very large residential land use developments. Because of this distorting size class, Growth-Pole municipalities show a lot of variation in the size of new residential areas.

In *VINEX municipalities*, over twice as many new residential land use developments have taken place during the period of study as in the Growth-Pole municipalities. When weighting the number of new developments by the area of the municipalities, the number of new residential land use developments is similar to that of Growth-Pole municipalities. The areas of new residential land use are large, but not as large as for the Growth-Pole municipalities. Nevertheless, as in the case of the Growth-Pole municipalities, the presence of a big-size class results in large variation in size of new residential land use developments.

In comparison to the average municipality, there are almost half as many residential land use developments in the municipalities that are situated in the *National Landscapes*. When the numbers of residential land use developments are weighted by the area of the municipalities, they remain lower than the numbers for municipalities that have no specific policy. The size of the largest residential land use developments in the municipalities with National Landscape policy is below the national average. With a small size of even the largest housing developments, the variation in the size of the new developments is obviously also low.

In the municipalities that are covered by the *National Ecological Network*, there is nearly the same number of residential land use developments as in the municipalities in the National Landscapes. When weighted by the area of the municipalities, the amount of new residential developments is clearly lower than in any of the other groups of municipalities. The size of the new residential land use developments is by far smaller than in any of the other groups of municipalities. This also results in a very low variation of size for the residential land use developments that take place in these municipalities.

In chapter 2, hypotheses were formulated regarding the metric values for the different groups of municipalities. These hypotheses can now be compared to the calculated metric values (Table 4.1).

Table 4.1: Expected outcomes and observed values for the different metrics for each group of municipalities

		NORM	G-P	VINEX	NL	NEN	G-P&VI
	N=	*392*	*9*	*45*	*18*	*18*	*7*
UPFI	*expected*	0	++	+	-	--	
	observed	88	103	223	55	56	223
AWPFI	*expected*	0	+	+	-	--	
	observed	128	268	223	120	86	270
RAWPFI	*expected*	0	+	-	0	0	
	observed	119	77	90	146	105	105
ILPI	*expected*	0	+	++	-	--	
	observed	137	883	425	98	68	434
PSDI	*expected*	0	+	+	-	--	
	observed	83	292	231	39	38	304
APRI	*expected*	0	+	++	-	--	
	observed	88	131	121	73	72	134

In broad lines most metrics meet the hypotheses. However, the extent to which the metric value is larger or smaller than values for municipalities with no specific policy does not meet the hypotheses in some of the cases. If we ignore the *extent* of difference between policy and non-policy municipalities, almost all hypotheses can be accepted as to forecasting higher or lower values for policy municipalities (allocation or restrictive policy) compared to non-policy municipalities. The Residential Area Weighted Patch Frequency Index provides an exception as it proves most of the hypotheses regarding this metric wrong.

4.2 A closer look at the metrics

This section will take a closer look at the calculated values for the metrics. Firstly, it will cover the frequency distributions for metric values. Secondly, it will analyse the implications of the outcomes for the groups of municipalities. Thirdly and finally, this section will analyse if there is correlation between the metrics.

4.2.1 Frequency distributions

In describing the frequency distribution of values for the different metrics one can be brief. For readers that are slightly unfamiliar with statistics, a basic statistical reference section is included in Appendix I. The different metrics show rather similar distributions. All distributions show a strong skew to the right, indicating that the vast majority of the observed values are in the lower region of the range of observed values. The largest portion of the municipalities thus has quite similar values for the metrics and there is a rather small group with more extreme high values. This is most clear with the Indexed Largest Patch Index, which resembles the shape of an exponential distribution. The variation in frequencies of observed values is greatest with the Area Perimeter Ratio Index (while the span of the observed value is smallest), which comes closest to a normal, bell shaped, distribution. Histograms of the frequency distributions for all metrics can be found in Appendix J.

4.2.2 Implications for the analysis

As values have been calculated for all municipalities, data are available for the entire research population. This means that there is no need to perform statistical tests to prove significance of difference (Vocht, 2004). Moreover, according to the rules of statistics it is inappropriate to calculate statistics over the entire population. Instead of using statistics, tables of differences are provided. These tables give an insight in the differences in metric values between all the groups of municipalities.

Besides the tables of differences, the distribution of values per metric is analysed for the different groups of municipalities. The metrics have been calculated on the interval measurement scale, the Boolean values for the Growth-Pole and the VINEX municipalities can be considered to be of nominal measurement scale and the percentages of restrictive policy are calculated on the ratio measurement scale. These differences in measurement scale have implications for the means that can be used to analyse these groups.

For the allocation policies, box and whisker diagrams will be used to compare the different groups. This will provide an insight in the medians and distributions of metric values between the different groups of municipalities with allocation policies and the municipalities with no specific policy.

Since the percentage of restrictive policies is measured on ratio measurement scale, it would be a waste of information to convert the values to nominal scale and analyse it in box-and-whisker diagrams. In order to prevent a reduction of information for the restrictive policies, the metrics will be analyzed in relation to the amount of restrictive policy in each municipality using scatter diagrams. However, the municipalities that are in National Landscapes have a very unbalanced frequency distribution for the percentage of the municipal surface that is in a National Landscape. There are very many municipalities that are not in a National Landscape, some municipalities that are completely in a National Landscape and very few municipalities that are in between. This results in scatter plots that provide very little information, therefore these scatter plots are not displayed. As a reference, the scatter diagrams for the National Landscapes can be found in Appendix K.

4.2.3 Correlation

For exploring relations between the metrics correlation is analysed. In order to be suited for calculating correlation coefficients (Pearson's r), the input data have to be bivariate-normally distributed. This is not the case for the metrics; therefore the non-parametric Spearman's rank correlation coefficient has been calculated. Spearman's ρ (rho) can be interpreted similarly to Pearson's r, $0 \leq \rho \leq 1$ for a positive relationship and $-1 \leq \rho \leq 0$ for a negative relationship. Spearman's ρ of 0 indicates that there is no relationship between the variables, a value of 1 indicates a perfect positive relationship and a value of -1 indicates a perfect negative relationship. However Spearman's ρ does, in contrast to Pearson's r^2, not give an insight into the percentage of variation for the variable on the y-axis of a scatter diagram that is explained by the variable on the x-axis. The values for Spearman's ρ between all metrics are displayed in Table 4.2.

Table 4.2: Spearman's ρ values as an indication of the correlation between the metrics

	UPFI	AWPFI	RAWPFI	ILPI	PSDI	APRI
UPFI	1	0.28	0.22	-0.08	0.20	0.08
AWPFI	0.28	1	-0.05	0.65	0.22	0.16
RAWPFI	0.22	-0.05	1	-0.27	-0.21	-0.26
ILPI	-0.08	0.65	-0.27	1	0.76	0.75
PSDI	0.20	0.22	-0.21	0.76	1	0.96
APRI	0.08	0.16	-0.26	0.75	0.96	1

The table with values for Spearman's ρ shows strong correlations (0.75 – 0.96) between the Indexed Largest Patch Index, the Patch Size Distribution Index and the Area Weighted Patch Frequency Index. This means that if a municipality has a high value for one of these thee metrics, it is very likely that the values for the other two metrics are high as well. The Area Weighted Patch Frequency Index does show moderate strong correlation with the

Indexed Largest Patch Index. This means that if there are a lot of new patches per unit of area, the largest patch is likely to be large. The Un-weighted Patch Frequency Index and the Residential Area Weighted Patch Frequency Index do not correlate with any of the other metrics. The Residential Area Weighted Patch Frequency is the only metric that has negative correlation (although it is weak) with all the other metrics. This indicates that the Residential Area Weighted Patch Frequency tends to be low where the other metrics are high.

The correlations found indicate that the Area Weighted Patch Frequency Index is likely to give an indication of the value for the Indexed Largest Patch Index. The Patch Size Distribution Index gives a rather strong indication of the values of the Indexed Largest Patch Index and the Area Perimeter Ratio Index. Because of this strong relationship, the Indexed Largest Patch Index, Patch Size Distribution Index and the Area Perimeter Ratio Index will be analysed together in the following section.

4.3 Results achieved by the metrics

This section analyses the results in depth by comparing metric values for the different groups of municipalities. Firstly the values for the metric on number of patches, the Un-weighted Patch Frequency Index, will be analysed. Secondly, values for metrics that relate the number of patches to area, the Area Weighted Patch Frequency Index and the Residential Area Weighted Patch Frequency Index, are studied more closely. Finally the metrics that give an indication of patch size and shape, the Indexed Largest Patch Index, Patch Size Distribution Index and the Area Perimeter Ratio, are analysed.

4.3.1 Number of new residential land use developments

The Un-weighted Patch Frequency Index gives an indication of the number of new residential land use patches in each municipality. The larger the value is the more new patches of residential land use have been observed.

4.3.1.1 Results for the Un-weighted Patch Frequency Index

Regardless of area more patches of new residential land use have been realised in municipalities with allocation policies than in other municipalities. It was expected that more patches had been realised in municipalities with Growth-Pole policy than in municipalities with VINEX policy. This turned out to be untrue: in municipalities with VINEX policy substantially more (117% higher metric value) patches have been realised than in municipalities with Growth-Pole policy. This shows that there might be less of a lack in implementation time for the VINEX policy than expected, or a very rapid development after the start of the VINEX construction works. On the other hand it could indicate that at the chosen cell size the VINEX residential development is more fragmented than expected. As said before, the municipalities with restrictive policies have lower values for the Un-weighted Patch Frequency Index than other municipalities. The differences that were expected between the national landscape municipalities and the National Ecological Networks municipalities are unconfirmed by the metric values (only 2% difference in metric value). This might indicate that the policy in the national landscape municipalities is stricter than expected, but it might also mean that the policy in national ecological landscape municipalities is not as strict as expected (Table 4.3). Note that the area of the municipalities or the areas of patches within municipalities are not weighted in this metric.

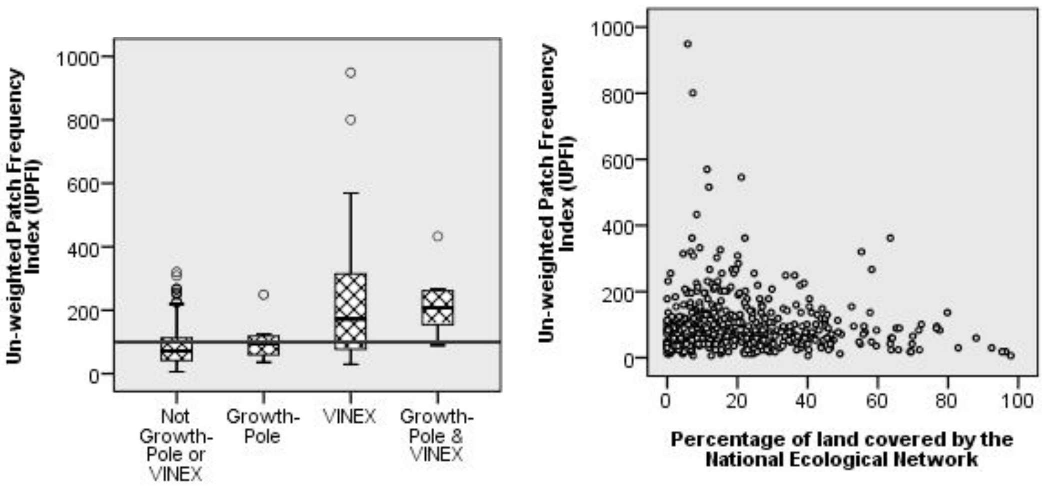
Table 4.3: Table of differences for the Un-weighted Patch Frequency Index (Column to row values, in percentages)

UPFI	**NORM**	**G-P**	**VINEX**	**NL**	**NEN**	**G-P&VI**
NORM	0	17	154	-37	-36	154
G-P	-15	0	117	-46	-45	117
VINEX	-61	-54	0	-75	-75	0
NL	59	87	305	0	2	305
NEN	56	82	296	-2	0	296
G-P&VI	-61	-54	0	-75	-75	0

The box-and-whisker diagram (Figure 4.1. left) shows that especially for the municipalities with no allocation policy, the distribution of observed values is rather positively skewed. This means that the mass of the observed values is quite low in the range of observed values. The same applies to the VINEX municipalities, although to a lesser extent. One can observe that the 25 percent of the observations for the VINEX municipalities with the highest values (top whisker plus outliers) have higher values for the Un-weighted Patch Frequency Index than almost all observations in all other groups.

The scatter diagram (Figure 4.1, right) shows that the municipalities with a high percentage of National Ecological Network area tend to have lower values for the Un-weighted Patch Frequency Index. The mass of the observed values seems to be on a rather horizontal line, but there are far more high outliers in the low percentages of National Ecological Network area. For the municipalities mostly covered by National Landscapes this also seems to be the case, but not as clearly as for the National Ecological Networks. This is in line with the findings for the group of municipalities that have the highest percentage of restrictive policies, as for those municipalities the average Un-weighted Patch Frequency Index value is low compared to other groups of municipalities.

Figure 4.1: Un-weighted Patch Frequency Index – results(Box-and-whisker diagram for allocation policies; scatter diagram for restrictive policies)



4.3.2 New residential land use developments weighted by area

In this section the results for the metrics that analyse the number of patches weighted by area are analysed. These metrics are the Area Weighted Patch Frequency Index and the Residential Area Weighted Patch Frequency Index.

4.3.2.1 Results for the Area Weighted Patch Frequency Index

The Area Weighted Patch Frequency Index indicates the number of new residential land use patches per municipality normalised by the area of the municipality. Through normalising the number of new patches by the area, municipalities with different surface size can be compared. A higher value for the Area Weighted Patch Frequency Index indicates that a municipality has relatively many new patches of residential and use per unit of area.

The values for the Growth-Pole and VINEX municipalities are higher than for other municipalities, but the difference between the two groups is relatively small (VINEX metric value is 20% larger than the metric value for Growth-Poles) (Table 4.4). This means that both Growth-Pole and VINEX municipalities have relatively many new patches of residential land use per unit of area. As expected, there are lower values for the Area Weighted Patch Frequency Index in the municipalities with restrictive policy than in other municipalities. Municipalities covered by the National Ecological Network have even lower values for the Area Weighted Patch Frequency Index than municipalities covered by National Landscapes.

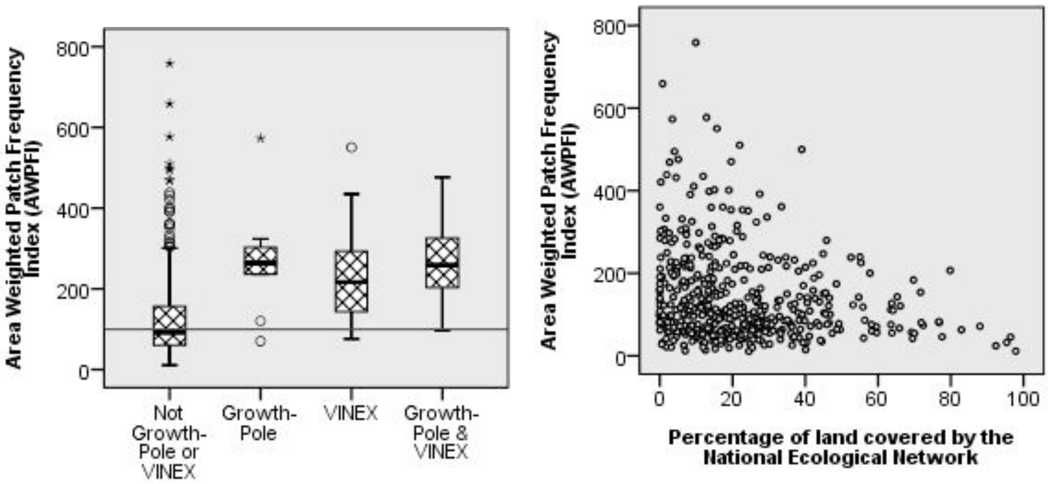
Table 4.4: Table of differences for the Area Weighted Patch Frequency Index (column to row values, in percentages)

AWPFI	**NORM**	**G-P**	**VINEX**	**NL**	**NEN**	**G-P&VI**
NORM	0	109	75	-7	-33	111
G-P	-52	0	-17	-55	-68	1
VINEX	-43	20	0	-47	-61	21
NL	7	124	87	0	-28	126
NEN	49	211	160	39	0	214
G-P&VI	-53	-1	-17	-56	-68	0

The range of observed Area Weighted Patch Frequency Index values for the municipalities without allocation policies is greater that the range of Area Weighted Patch Frequency Index values for the other groups (Figure 4.2, left). While the median is very low compared to the other groups, there is a long string of outliers and extreme outliers higher in the value range. A logical explanation for this seems that the smallest municipalities are in the group with no allocation policy and if a municipality is very small a low number of new patches can result in a high value for the Area Weighted Patch Frequency Index. Compared to the VINEX municipalities, the median of the Growth-Pole municipalities is rather high, but the total span of the observed values for VINEX municipalities and Growth-Pole municipalities is about the same. The median of the group of municipalities without allocation policy is clearly lower than the medians of the other groups. The mass of the values is as low as the 25 percent of lowest values for the other groups.

For the Area Weighted Patch Frequency Index the values are less clustered in the lower value region than for the Un-weighted Patch Frequency Index (Figure 4.2, right). Again the observed values tend to be lower for the municipalities with a higher percentage of land surface in the National Ecological Network compared with municipalities with a lower percentage of their land under the National Ecological Network. For the National Landscapes this pattern is less clear, as the municipalities with high values for the percentage of National Landscapes show much variation in the values for the Area Weighted Patch Frequency Index.

Figure 4.2: Area Weighted Patch Frequency Index – results (box-and-whisker diagram for allocation policies; scatter diagram for restrictive policies)



4.3.2.2 Results for the Residential Area Weighted Patch Frequency Index

The Residential Area Weighted Patch Frequency Index indicates the amount of new residential land use patches normalised by the area of existing residential land use in the same municipality. A high value for the Residential Area Weighted Patch Frequency Index indicates that per unit of area of existing residential land use relatively many new patches of new residential land use have been observed. By normalising the number of new residential land use patches by the existing area of residential land use, more urban municipalities can be compared to more rural municipalities.

Growth-Pole municipalities have the lowest values for the Residential Area Weighted Patch Frequency Index (36% lower metric values than the municipalities with no specific policy) (Table 4.5). This indicates that there might have been more existing area of residential land use in the Growth-Pole municipalities than expected on first hand, or the number of new patches in the Growth-Pole municipalities might have been overestimated. Most likely it is a combination of these two factors that causes the low Residential Area Weighted Patch Frequency Index value for the Growth-Pole municipalities as the Un-weighted Patch Frequency Index was lower than expected for this group but still higher than the national average. As expected, the value for the VINEX municipalities is lower than the average (24% lower metric value). This is likely to be caused by the relatively large area of existing residential land use in these municipalities, as the Un-weighted Patch Frequency Index values are relatively high. The municipalities covered by National Landscapes have a surprisingly high value for the Residential Area Weighted Patch Frequency Index (23% higher metric values than the municipalities with no specific policy). As the UPFI value for these municipalities is relatively low, this is likely to be caused by a much lower area of residential land use in these municipalities than expected, boosting the Residential Area Weighted Patch Frequency Index value. The value for the Residential Area Weighted Patch Frequency Index for municipalities covered by the National Ecological Network is slightly further away from the value of the municipalities with no specific policy that expected before. As the UPFI is lower than that of the average municipality, this might be caused by a slight underestimation of the amount of residential area in these municipalities. However, the differences are not very large (12%).

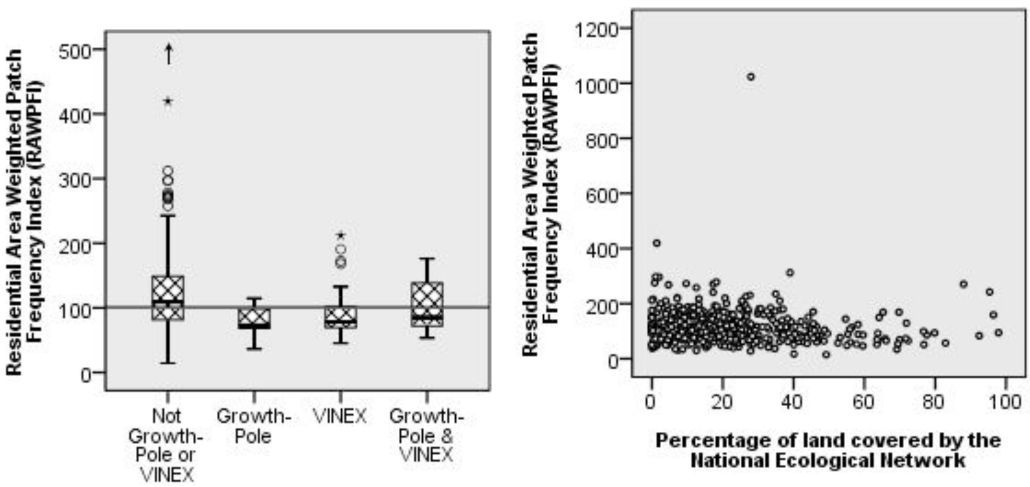
Table 4.5: Table of differences for the Residential Area Weighted Patch Frequency Index (Column to row values, in percentages

RAWPFI	NORM	G-P	VINEX	NL	NEN	G-P&VI
NORM	0	-36	-24	23	-12	-12
G-P	55	0	18	90	37	37
VINEX	32	-15	0	62	16	16
NL	-18	-47	-38	0	-28	-28
NEN	13	-27	-14	39	0	0
G-P&VI	13	-27	-14	39	0	0

There is far less variation in the values for the Residential Area Weighted Patch Frequency Index between the different groups of municipalities than there is for other groups. It is notable that the median for the municipalities with no allocation policy is higher than the medians for the other groups, in contrast to the other metrics (Figure 4.3, left). The low amount of variation could indicate that the amount of new residential area is strongly related to the existing residential area. The slightly lower values for the municipalities with allocation policies could indicate that these municipalities have a large base of residential area in the beginning of the temporal span of this research. This could explain why these municipalities have low values for the Residential Area Weighted Patch Frequency Index while the Un-weighted Patch Frequency Index values are relatively high.

The Residential Area Weighted Patch Frequency Index is the only metric for which the municipalities with restrictive policies show higher values (which is not strange as these municipalities are assumed to have less residential area) (Figure 4.3, right). There is no clear directional pattern in the relation between the Residential Area Weighted Patch Frequency Index and the percentage (of municipal surface) of National Landscapes or National Ecological Network. If a line would be fitted through the data points it would be nearly horizontal. This could indicate that the existing stock of residential land use could be very much related to the amount of new residential land use.

Figure 4.3: Residential Area Weighted Patch Frequency Index – results (box-and-whisker diagram for allocation policies; scatter diagram for restrictive policies)



4.3.3 Size and shape of residential land developments

In this section the results for the metrics that give an indication of the size and shape of new residential land use developments are discussed. These metrics are the Indexed Largest Patch Index, the Patch Size Distribution Index and the Area Perimeter Ratio Index.

4.3.3.1 Results for the Indexed Largest Patch Index

The Indexed Largest Patch Index gives an indication of the size of the largest observed patch of new residential land use in a municipality. A high value for the Indexed Largest Patch Index indicates that the size of the largest observed patch of new residential land use in the municipality is large compared to the national average.

As expected the Indexed Largest Patch Index is high for the municipalities with allocation policies and low for municipalities with restrictive policies. What is surprising is that the Indexed Largest Patch Index for the Growth-Pole municipalities is much higher than for VINEX municipalities (108% higher metric value) (Table 4.6). VINEX municipalities are famous or notorious for their large-scale new residential areas. Possibly this much higher value is caused by the chosen cell size causing large residential areas to be split by roads. Another possibility is that the development of residential areas in the Growth-Pole municipalities is more concentrated than it was expected to be. In line with the expectations, the Indexed Largest Patch Index values for the municipalities covered by the National Ecological Network are lower than the values for the municipalities with no specific policy (50% lower metric value) and municipalities covered by the National Landscapes (30% lower metric value).

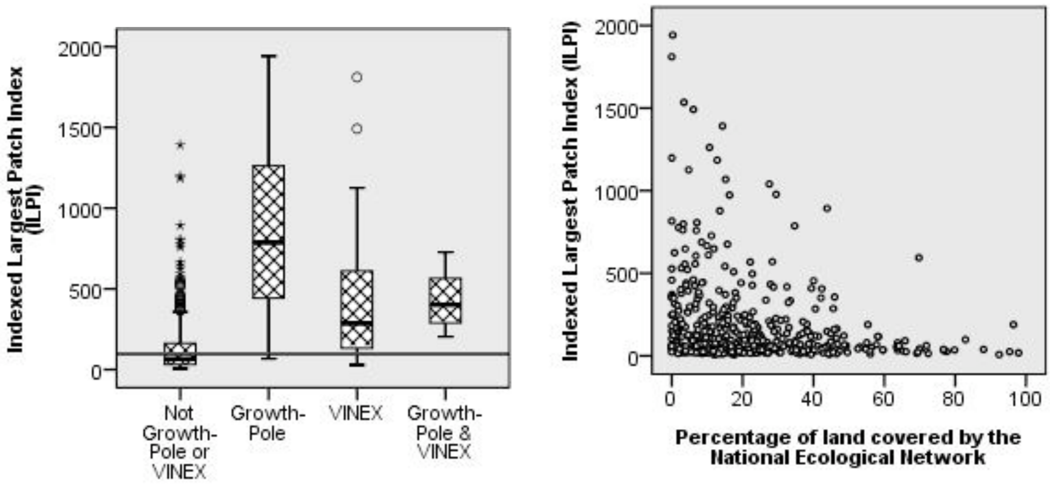
Table 4.6: Table of differences for the Indexed Largest Patch Index (column to row values, in percentages)

ILPI	**NORM**	**G-P**	**VINEX**	**NL**	**NEN**	**G-P&VI**
NORM	0	543	209	-29	-50	216
G-P	-84	0	-52	-89	-92	-51
VINEX	-68	108	0	-77	-84	2
NL	40	802	334	0	-30	344
NEN	101	1190	520	43	0	534

The distribution of observed Indexed Largest Patch Index values for the municipalities without allocation policy has a quite strong positive skew (Figure 4.4, left). The median for the Growth-Pole municipalities is clearly higher than the means of other groups. However, the gross of the values of the VINEX municipalities is still higher than the third quartile for the municipalities without allocation policy. This indicates that the absolute size of the largest patches is clearly higher in municipalities with allocation policies than in municipalities with no allocation policy. It is also notable that this metric shows the largest range of observed values, up to almost 2000 (where the national average is indexed at 100).

Although the mass of the observed Indexed Largest Patch Index values are concentrated in the lower region, it is clear that there is a larger amount of relatively high values in the municipalities that have a lower percentage of their area covered by the National Ecological Network (Figure 4.4, right). Looking at the scatter diagram, there seems to be a trend of decline of the Indexed Largest Patch Index value with an increasing percentage of the municipal area covered by National Ecological Networks. This is in line with the expectations as large patches were not foreseen in the municipalities that are most covered by restrictive policies. Because the range of values is larger for this metric than it is for others, the variation in the lower region is harder to observe. The municipalities with the lowest percentage of their land surface in a National Landscape also tend to have higher values for the Indexed Largest Patch Index.

Figure 4.4: Indexed Largest Patch Index – results (box-and-whisker diagram for allocation policies; scatter diagram for restrictive policies)



4.3.3.2 Results for the Patch Size Distribution Index

The Patch Size Distribution Index gives an indication of the extent to which the sizes of the patches of new residential land use differ within a municipality. A high number indicates that there is much variation in the sizes of the observed patches of new residential housing in the municipality.

There is a large variation in the sizes of the different patches of new residential area within municipalities in the Growth-Pole and VINEX groups (high Patch Size Distribution Index values) (Table 4.7). The variation of patch sizes within the municipalities (partly) covered by National Landscapes and by the National Ecological Network is smaller than in the average municipality (52% and 54% lower metric values than municipalities with no specific policy).

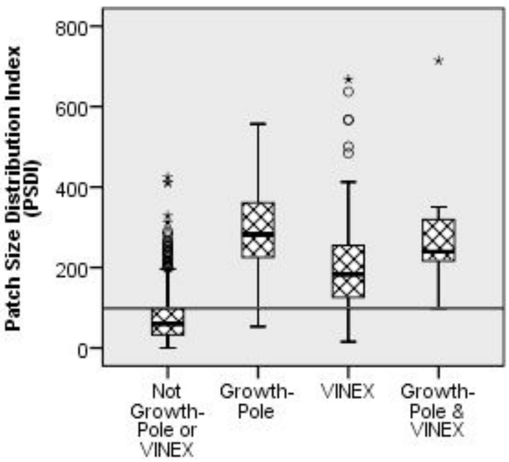
Table 4.7: Table of differences for the Patch Size Distribution Index (column to row values, in percentages)

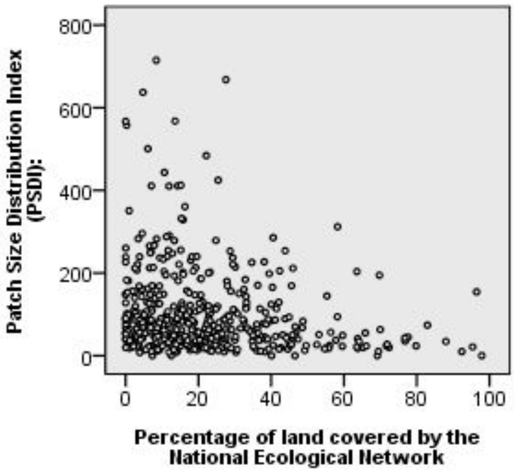
PSDI	**NORM**	**G-P**	**VINEX**	**NL**	**NEN**	**G-P&VI**
NORM	0	253	179	-52	-54	267
G-P	-72	0	-21	-87	-87	4
VINEX	-64	26	0	-83	-84	32
NL	110	641	487	0	-4	672
NEN	119	672	511	4	0	703
G-P&VI	-73	-4	-24	-87	-88	0

The observed values for the Patch Size Distribution Index show a strong positive skew for the municipalities with no allocation policy, like the Indexed Largest Patch Index and the Area Weighted Patch Frequency Index (Figure 4.5, left). It is likely that this is caused by the relatively strong correlation between these metrics. For the VINEX municipalities and even more for the Growth-Pole municipalities, the medians are clearly higher than the median for the municipalities with no allocation policy. This indicates that there is more variation in patch size in the VINEX and Growth-Pole municipalities as there is in municipalities with no allocation policy. This is not vey surprising as for the VINEX and Growth-Pole municipalities the Un-weighted Patch Frequency Index and the Indexed Largest Patch Index were higher. This means that there are more observed patches in these municipalities and that the size of the largest patches is bigger. This leads to greater variation in patch size (although a high patch frequency could also lead to lower standard deviations).

It is not very surprising that the distribution of observations is somewhat similar to the distribution of the Indexed Largest Patch Index observations, as the variation in size of patch is to an important degree caused by the size of the largest patch. Furthermore, the analysis of correlation shows that these metrics are strongly correlated. Higher values for the Patch Size Distribution Index occur most frequently at municipalities that have a lower percentage of their surface covered by the National Ecological Networks (Figure 4.5, right). The same is valid for the National Landscapes, but to lesser extent.

Figure 4.5: Patch Size Distribution Index – results(Box-and-whisker diagram for allocation policies; scatter diagram for restrictive policies)





4.3.3.3 Results for the Area Perimeter Ratio Index

The Area Perimeter Ratio Index gives an indication of the units of patch area per unit of patch perimeter for the patches of new residential land use in a municipality. If a patch has many units or area per unit of perimeter, the patch has a relatively compact form and / or is relatively large. A high value for the Area Perimeter Ratio Index thus indicates that the patches in a municipality are relatively compact and / or large.

There are no notable differences in the values for the Area Perimeter Ratio Index between the Growth-Pole and the VINEX municipalities (8% higher metric value for Growth-Pole municipalities) or between the municipalities covered by National Landscapes and municipalities covered by the National Ecological Network (Difference of 1%) (Table 4.8). Although these differences do not occur, the general hypothesis that the patches in the municipalities with allocation policies are larger or more complex than in the average municipality and that the opposite counts for the municipalities with restrictive policies, is proven to be true by the values for the Area Perimeter Ratio Index.

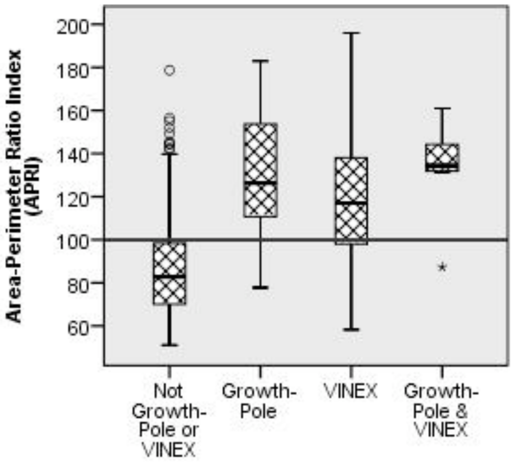
Table 4.8: Table of differences for the Area Perimeter Ratio Index (column to row values, in percentages)

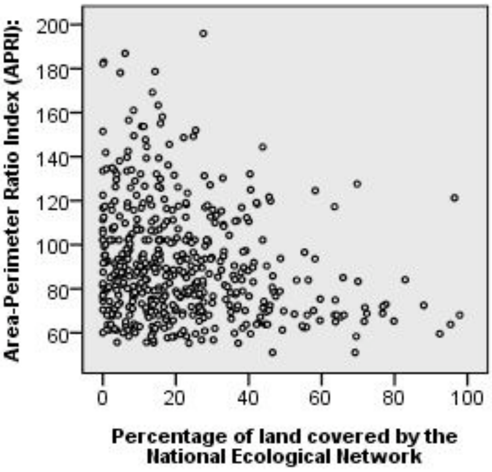
APRI	**NORM**	**G-P**	**VINEX**	**NL**	**NEN**	**G-P&VI**
NORM	0	49	38	-17	-18	52
G-P	-33	0	-8	-45	-45	2
VINEX	-28	8	0	-40	-41	10
NL	21	80	67	0	-1	83
NEN	22	82	68	1	0	85
G-P&VI	-34	-2	-9	-45	-46	0

The vast majority of the observed Area Perimeter Ratio Index values for the municipalities with no allocation policy are below the national average level. This means that the patches of new residential land use do not have an as compact form (smaller patches generally have more perimeter per area than larger patches) as in municipalities with allocation policies (Figure 4.6, left). Compared to the metrics the range of observed Area Perimeter Ratio Index values is relatively short, with the highest value just below 200.

It is clearly visible that there is correlation between the percentage of municipal land covered by the National Ecological Network and the Area Perimeter Ratio Index (Figure 4.6, right). Municipalities with less area covered by the National Ecological Network tend to have higher values for the Area Perimeter Ratio Index. This is not very surprising as the Patch Size Distribution Index and the Indexed Largest Patch Index show a similar trend. For the National Landscapes, no clear trend can be observed.

Figure 4.6: Area Perimeter Ratio Index – results (box-and-whisker diagram for allocation policies; scatter diagram for restrictive policies)





4.4 Overview of the results

Municipalities with allocation policy (pro new residential area) show higher values for nearly all metrics than other municipalities. The Residential Area Weighted Patch Frequency Index forms an exception, as expected. This means that the municipalities that have an allocation policy have:

- relatively many patches of new residential land use,
- relatively many new patches of residential land use per unit of area
- relatively few new patches per unit of existing residential area,
- relatively large new patches of residential land use,
- relatively large variation in the size of the new residential land use patches and
- relatively many units of area per unit of perimeter per new patch.

Overall, this is all according to the expectations prior to analysis of the results. The Growth-Pole municipalities deviate most from the expectations by having a lower number of new patches and larger new patches than expected.

The municipalities that have restrictive policies (con new residential area) show lower values on each metric except for the Residential Area Weighted Patch Frequency Index. This was also mostly in line with the expectations. Especially the group of municipalities covered by the National Ecological Network stands out by having lower than normal values for all of the metrics. The group of municipalities covered most (as a percentage of their surface) by the National Landscapes deviates most from the expectations by having a much higher than expected value for the Residential Area Weighted Patch Frequency Index. This is likely to be caused by a lower initial area of residential land use than expected.

The frequency distributions for the observed values of all metrics are clearly skew to the right. This means that there is a relatively large portion of the observations that have a relatively low value and relatively few observations with a high value. The largest span in observed values can be found with the Indexed Largest Patch Index and the smallest range can be found with the Area-Perimeter Ratio Index.

The groups of municipalities with allocation policy do clearly discriminate from the group of municipalities with no allocation policy with most metrics. Exceptions are the group of Growth-Pole municipalities that is quite close to the group of municipalities with no allocation policy with the Un-weighted Patch Frequency Index and all groups with the Residential Area Weighted Patch Frequency Index. The Residential Area Weighted Patch Frequency Index is actually quite interesting as on first sight the existing area of residential land use seems to be very much related to the amount of patches of new residential land use.

It remains very hard to find trends in the relation between the metrics and the percentage of land covered by the National Landscapes. This is caused by the distribution of percentages of national landscape per municipality; the vast majority had zero percent and a small group had over ninety. Generally it seems to be true that with higher percentages of municipal land surface under National Landscapes lower metric values are observed except for the Residential Area Weighted Patch Frequency Index. The distribution of the percentage of national ecological landscapes shows more variation, the scatter plots are generally readable. The observations do not allow for linear regression analysis, as the residuals are not normally distributed. Overall there seems to be a linear or light exponential relationship between the percentage of National Ecological Network area and the metric values. A higher percentage of land covered by the National Ecological Network generally means that the metric value is lower. Again, the Residential Area Weighted Patch Frequency Index acts as an exception, as the metric values seem to be uninfluenced by the percentage of land covered by the National Ecological Network.

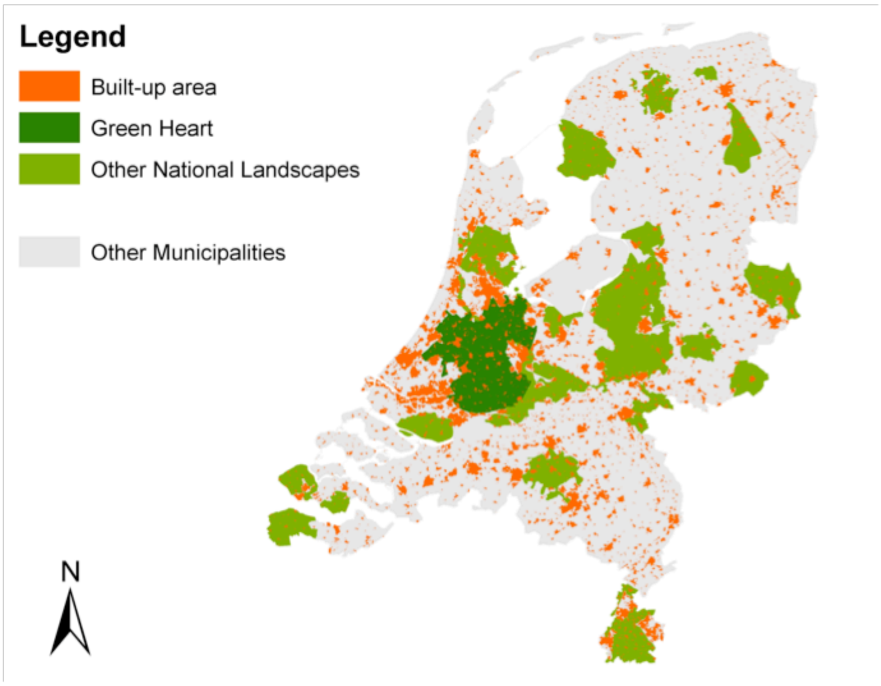
5 CASE STUDY GREEN HEART

5.1 Background

The success or failure of the green heart policy is a broadly discussed topic in the Dutch spatial planning (Beatley, 2001; Bontje, 2003; Cammen & Klerk, 2003; Koomen, Dekkers, & Van Dijk, 2008; Van Rij, Dekkers, & Koomen, 2008). The Green Heart is a National Landscape that is surrounded by the Randstad cities of which Amsterdam, Den Haag, Rotterdam and Utrecht are the largest (Figure 5.1). Because the Green Heart is surrounded by these cities there is a significant pressure caused by the continuous expansion of the surrounding cities on this green open area.

In this research project we have seen that overall – over the period 1993-2003 – there was a lower level of residential development in municipalities in National Landscapes compared to municipalities with no restrictive policy. It is interesting to compare Green Heart municipalities with municipalities in other National Landscapes. The pressure for development is obviously much bigger in the Green Heart. Do the general findings apply in this particular case? And can we find internal variation within the Green Heart on the basis of our data and analysis? Do municipalities at the edges of the Green Heart, very close to the surrounding cities, give way to development pressure more than municipalities in the middle of the Green Heart?

Figure 5.1: Built-up area, Green Heart and other National Landscapes in The Netherlands



5.2 Analysis

The analysis requires a grouping of municipalities. There is one group with municipalities that are completely within the Green Heart, there is a second group of municipalities that are within a National Landscape other than the Green Heart and the third group of municipalities is not completely contained by a National Landscape. For a large part, the boundaries of National Landscapes follow the municipal boundaries. However, due to different interpretation of these boundaries while digitising the National Landscapes, these boundaries are at places just a little different from the boundaries as they are on the municipal map. In order to avoid errors because of this issue, a buffer of 1 kilometre has been added to all the national landscapes.

Analysis of the metrics has shown that some of the metrics are more powerful than others. In this case study three of the six metrics introduced in this study are used and the other three metrics are omitted. The metrics that are used in this case are:

- Area Weighted Patch Frequency Index: this metric gives an indication of the amount of patches of new residential land use weighted by the area of a municipality.
- Indexed Largest Patch Index: this metric gives an indication of the largest patch of new residential area in a municipality.
- Patch Size Distribution Index: this metric gives an indication of the variation of size of patches of new residential land use in a municipality.

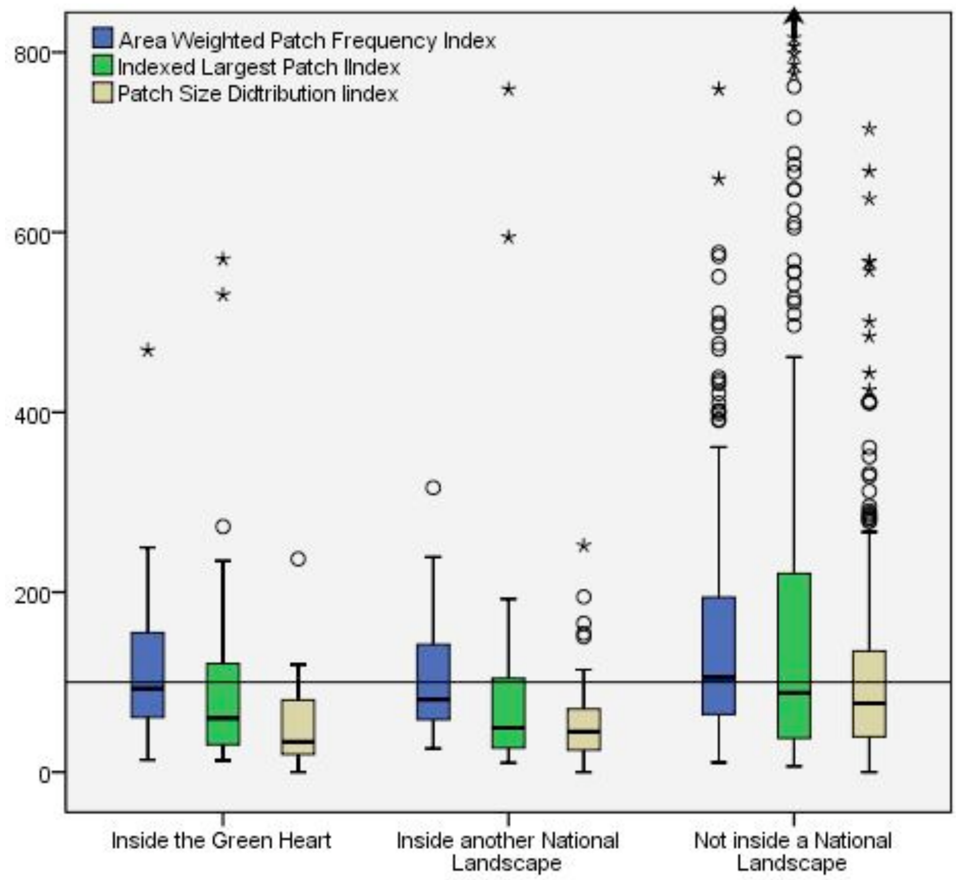
The values for these patches have already been calculated for all the municipalities in the Netherlands.

5.3 Metric values

The metric values, discussed in previous chapters, have shown that during the period 1993-2003 there was considerably less new residential development in the Green Heart and all other National Landscapes compared to all other municipalities (outside National Landscapes) (Figure 5.2). The differences between the Green Heart and the other National Landscapes are very slight. For the Green Heart and the other National Landscapes, the median value for the Area Weighted Patch Frequency Index is lower than the median for the other municipalities in the Netherlands. This indicates that in the Green Heart and in the other National Landscapes, weighted by municipal area, less patches of new residential land use have been developed than in other municipalities in the Netherlands. The Indexed Largest Patch Index shows that the size of the largest patch of new residential land use is overall considerably smaller in the Green Heart and in the other National Landscapes than it is in the municipalities in the rest of the Netherlands. The Patch Size Distribution Index finally shows that the variation in patch sizes is smaller in all of the National Landscapes than it is in the other municipalities.

In comparison with the other municipalities in the Netherlands, both in the Green Heart and in the other National Landscapes new residential land use has been developed in low frequencies, with relatively small patches and little variation in patch size. The differences between the Green Heart and the other National Landscapes are relatively small. In comparison to the other National Landscapes the medians of the values for the Area Weighted Patch Frequency Index and the Indexed Largest Patch Index are a little higher, the median for the Patch Size Distribution Index is a little lower. However, these differences are minor when compared to the differences between the two groups of National Landscapes and the rest of the municipalities in the Netherlands.

Figure 5.2: Comparison of metric values for the municipalities in the Green Heart, municipalities in other National Landscapes and municipalities not in National Landscape



Looking at these metric values it seems that the municipalities in the Green Heart have been as successful in withstanding the pressure of urban expansion as the municipalities in the other National Landscapes. This is surprising as the pressure of urban expansion on the Green Heart is much higher than on the other National Landscapes.

5.4 Methodological remarks

Because the metrics are calculated for entire municipalities, they do not give an insight in the variation within municipalities. Therefore, while grouping the municipalities, only municipalities that lay completely within the National Landscapes are labelled as a National Landscape or Green Heart municipality. This means that municipalities that lay partly in a National Landscape were not labelled as National Landscape municipality. Therefore, these metrics do not give an indication of what has happened on the borders of the Green Heart and the other National Landscapes in municipalities that are partly situated within the National Landscapes. There is a possibility that the Green Heart seems to withstand urban developments quite well (given the values of the metrics) but it might turn out that in reality there is lots of development in the municipalities that are only partly in the Green Heart. Such developments would be a threat to the Green Heart as parts of the National Landscape - close to its perimeter - might have been used for urban expansion.

For assessing such border pressure on the Green Heart, also compared to other National Landscapes, the Area Weighted Patch Frequencies have been mapped (Figure 5.3 and Figure 5.4). Two maps were created, one of the values for the Area Weighted Patch Frequency Index in the Green Heart and its surroundings and one with the values around other National Landscapes. The maps have the exact same classification scheme for the Area Weighted Patch Frequency Index. Looking at the maps it is instantly very clear that the pressure of urban developments is significantly stronger on the Green Heart than it is on the other National Landscapes. It remains unclear to what extent these developments take place within the borders of the Green Heart or just outside these borders.

This case shows that the calculated metrics work well on municipal scale, but in the way they are calculated at this moment they seem to be less suitable to assess processes that take place at higher scale levels. For analysis within municipalities, the metrics can be calculated at another level of administrative boundaries, for example for neighbourhoods. This could potentially give a more detailed answer to the question to what extent residential land use development has taken place within the boundaries of National Landscapes.

Figure 5.3: Area Weighted Patch Frequency Index: municipalities in and in the surroundings of the Green Heart

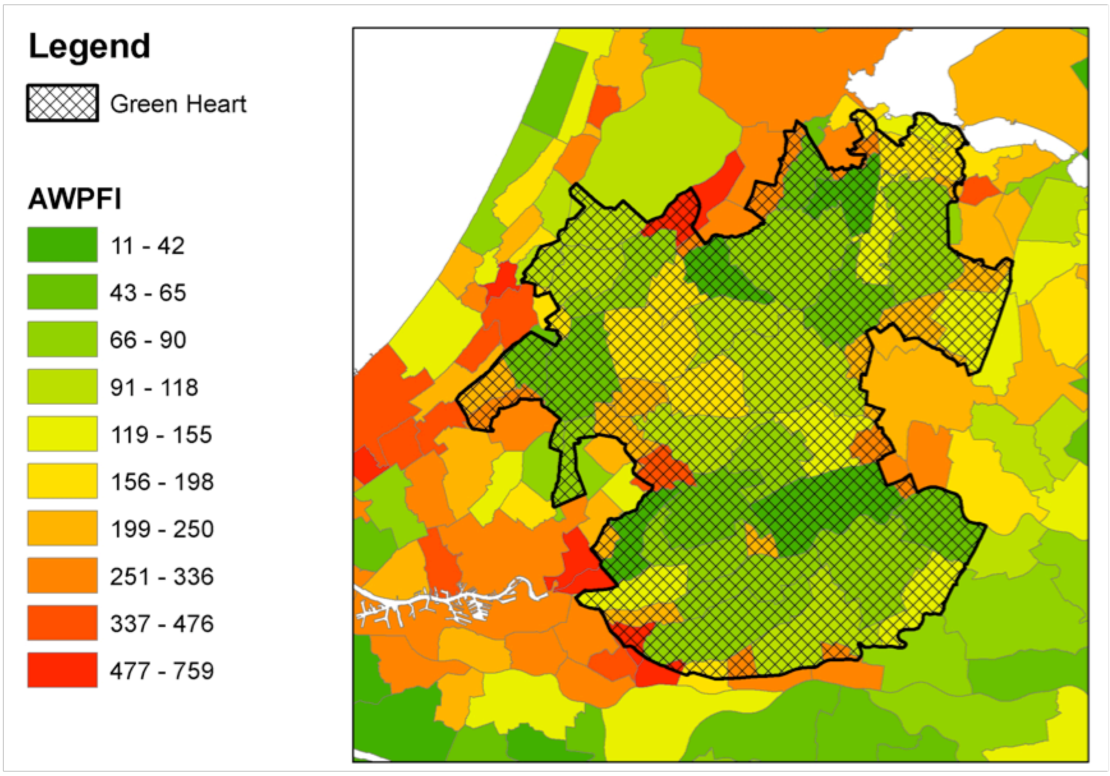
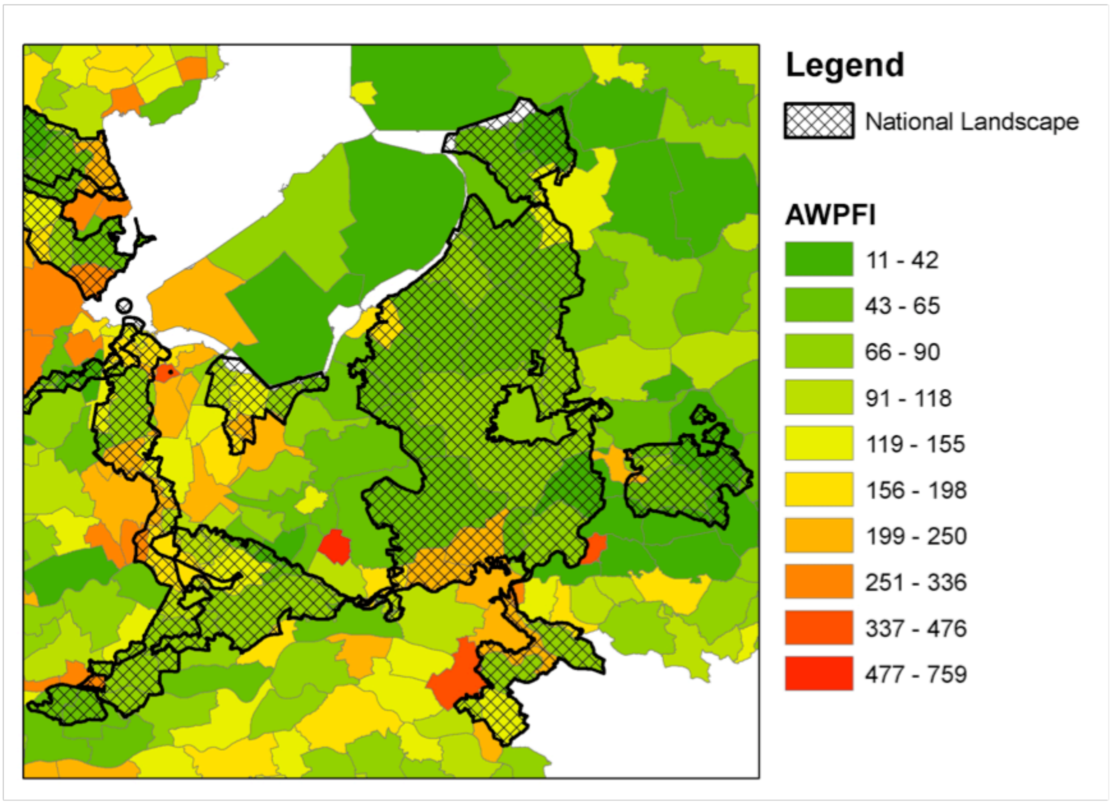


Figure 5.4: Area Weighted Patch Frequency Index: municipalities in and in the surroundings of some National Landscapes other than the Green Heart



6 DISCUSSION

6.1 Distinctive features of this research

This research project is unique in the sense that it looks at processes of land use change and the driving forces behind these changes. In the field of land use modelling it is common practice to derive decision rules from map comparison. By comparing maps for years A and year B the mathematical functions for the change of each land use class can be calculated. These functions may then be used to extrapolate land use change of the past into the future. This approach to land use modelling provides quite detailed functions for the change of different classes of land use and it is very time efficient. However, it does not give any insight in the driving forces that are responsible for the change of land use for the different classes. This means that it is hard to provide a theoretical basis for the observed mathematical functions that forecast land use change. In this research project a different approach was followed. Theory has indicated that planning policy is very likely to be one of the driving forces of land use change. In this research project hypotheses were formulated based on national planning policy in the Netherlands for the construction of new residential areas; these hypotheses were then tested through map comparison. By following this methodology, map comparison does not provide mathematical functions as input of a model but it is used to assess the effects of policy on the observed changes of residential land use. The results clearly show discrimination between different groups of municipalities with different policies on residential land use development. Municipalities subject to national residential growth policy show more new patches of residential land use than municipalities under a restrictive national residential development regime. These patches also tend to be larger in the municipalities that have a pro-new residential area policy.

6.2 Discussion of the methodology

The methodology as used in this study has proven to be suitable for this kind of research. First, expectations or hypotheses were formulated regarding the expected changes in land use based on literature study. Second, metrics were selected or formulated to test these hypotheses. Third, the metric values were calculated by comparing digital maps. And finally the observed metric values were used to test the hypotheses. While this methodology has proven to be a successful approach for this study, there are several considerations that deserve some extra attention:

- While formulating the hypotheses regarding the change of land use it is important that these hypotheses can be tested by metrics using the available data. Therefore it is important to keep in mind if the data could answer the hypotheses while selecting the data.
- If custom-made metrics are used for the study, no past experience on the behaviour of metrics are available. It may be the case, therefore, that these metrics show strong correlation or that they do not discriminate between groups as expected.
- It often is very hard to find datasets that represent two moments in time that have the same classification and spatial scale. Advances in technology allow for the creation of more and more detailed maps, which makes it hard to find two datasets with the same level of detail for two different years.
- The temporal scale or time frame of the research should be large enough to reflect the expected effects of the driving force of study. If, for example, the digital maps cover a period of 3 years, it will be hard to find changes in residential land use area that are plausibly caused by (changes in) national spatial policy: policies require long time spans to materialize on the ground.

- While comparing the "before" and "after" maps, the computational operation should be as simple as possible. The more complex the comparison is, the higher the chance that extra noise is introduced in the results.
- While keeping the computational operation as simple as possible in order to avoid adding noise, the operation should aim at reducing the noise that is introduced by the input datasets. When comparing vector datasets lots of sliver polygons can be introduced on places where boundaries of maps features differ slightly. These sliver polygons are differences in the two maps but they might not exist in the real world. Therefore a filtering mechanism of some kind should be incorporated in the comparison of the two maps in an effort to distillate the differences.
- When using a raster environment to prevent noise from sliver polygons to occur, it is important to take notice of the method of rasterising. A majority rule per cell prevents small sliver polygons from having an influence on the raster datasets. However, one should keep in mind that the conversion to raster could also introduce new errors.
- If the calculation is performed using raster datasets, it is important that the relationship between cell size, the object to be studied and the input data is assessed. For the quantification of residential land use developments, 50x50 meter raster cells have proven to introduce relatively much noise and 500x500 meter raster cells have proven to be unable to capture small residential developments. Analysis on results and noise can help to find the sweet spot in cell size.
- While analysing the metric values it is important to analyse the behaviour of the metrics. Frequency distributions can be used for testing the distribution of metric values over the objects of study and correlation analysis may be applied for assessing the relationships between individual metrics.
- If a sample of areas is drawn from the entire study area, results should be statistically tested for significance. This should be done for the metric values for different groups of study objects and for the correlations between the metrics as well.
- When the metric values have been calculated, it is important that a translation to the "real world" objects is made. What does a high value for metric "A" mean? In the exploration of the results the translation to the meaning of the metric values should be made regularly.
- It is important to stress that an analysis as conveyed in this research project excludes 'real world' causality. On the basis of the results is might be tempting to say that 'policy works': we found clear relationships between allocation and restrictive policies on the one hand and levels of new residential development at municipal level on the other hand. Even in the case study area of the Green Heart, where development pressure is high, restrictive policies appear to have been effective. Nevertheless, evidence for actual causality would require additional research of a very different kind, such as spatial policy and practice analysis at the level of a number of selected case study municipalities.

While the methodology used in this research have proven to be successful, one could argue for a methodology that is not depending on technology and data as much as the methodology that has been used in this study. Because GIS has a prominent role in this research, it is strongly depending on the availability of data and the boundaries of what is technically possible. In this research project this has not imposed any problems, but it could cause problems if similar research is done using larger datasets.

Finally, to gain more fundamental understanding in a complex phenomenon as the role of institution as a driving force of land use change, more methodological approaches should be combined. Combining a rather quantitative research methodology as applied in this study with a more qualitative research methodology might provide deeper understanding of institutions as driver for land use change. This could also provide a better understanding of causalities between the land use, policies and the change of land use.

6.3 Discussion of the metrics used

The amount of new residential land use patches is, as expected, quite strongly related to the total area of the municipality of study. This is proven by the differences in values between the Un-Weighted Patch Frequency Index and the Area Weighted Patch Frequency Index. This means that the results from the Un-weighted Patch Frequency Index should not be taken too seriously in isolation and be analysed in combination with the Area Weighted Patch Frequency Index.

The Residential Area Weighted Patch Frequency Index does not clearly discriminate between the groups. This means that the amount of new patches of residential area shows clear correlation with the total existing residential area in the municipalities. In relation to national policy this might indicate that more new residential land use areas are planned in municipalities with a larger existing base of residential area. However, this relation is not proven by this research.

The Indexed Largest Patch Index, Patch Size Distribution Index and the Area Perimeter Ratio Index are three metrics that give an indication of the size of patches of new residential land use. These three metrics are strongly correlated; therefore it is likely that the combination of these three metrics leads to a redundancy of information. However, these three metrics focus on different aspects of patch size. The Indexed Largest Patch Index solely takes the size of the largest new patch in each area of analysis into account. The Patch Size Distribution Index gives an indication of the distribution of all new patches in each area of study. The Area Perimeter Ratio Index gives and indication of patch size but it also gives an indication of patch shape complexity. In this project no successful distinction could be made between the indication of patch size and patch shape. Therefore the Area Perimeter Ratio Index could be considered to be superfluous, it could be omitted without losing information about the results. However, if combined with another metric on shape (which has not been done in this research), the Indexed Largest Patch Index could provide valuable insights.

6.4 Validity of the results

This research analysed the relationship between the Growth-Pole, VINEX, National Landscapes and National Ecological Networks policies and residential land use development. What we found in substantial terms is a number of clear relationships between policies and actual levels of residential development (although causality is excluded from the analysis, as discussed before). Does this mean that policy parameters could be included in land use models that have the ambition to predict future land use? A number of observations are in place in relation to this question:

- The inclusion of policy parameters in land use models (such as housing allocation policies or restrictive policies for landscape and/or nature protection) should always take into account the space-time context for which the policy parameters may be assumed to be valid. Predictive value is limited by the time horizon of the policy under consideration. Growth-Pole policy is no longer relevant in 2010 and VINEX policy equally will not have an eternal life. The same may apply to restrictive planning regulations: they will change over time in content and scope. Policy parameters may play a role in land use modelling, but only with caution about the place and time context in which these are valid. It basically means that application is possible over relatively short time horizons and in specific geographical setting (the country where the policy applies, for example).

- Land use modelling experts should be extremely cautious in including policy parameters in land use prediction models that are international in scope. Not only do spatial policies – such as allocation or restrictive policies – vary in detail, scope, and effectiveness between countries. But also the interplay between such policies and other context factors (such as political stability, economic dynamism, demographic pressure) will be different from country to country.
- The analysis of the relations between spatial policies and residential development in this project was retrospective. Clear relationships were found. This does not mean that similar relationships may be expected to occur if policy parameters were used in land use modelling with a prospective ambition: to predict future land use changes. Even if certain allocation or restrictive policies may reasonably be expected to be 'constant' into the near future (say for ten years), other context factors may change considerably into the future. The current economic and financial crisis is a good point in case. If the crisis would result in a severe downfall in private sector investment and/or public spending capacity, housing allocation policy (such as VINEX) might give a very different 'real world' picture compared to past years.

Furthermore, policy goes way beyond the number of new residential areas and their size. Policy goals usually also include targets for the numbers of houses, thereby giving an indication of the average density of residential units in a residential area. Furthermore, policy can have socio-economical goals like mixed land use, or set targets for the socio-economic profile of the inhabitants of new residential zones. The metrics that have been used in this research project does not allow for assessing such policy goals, but there are metrics that do allow for mixed use for example.

This research project should be seen as a small step towards a better understanding on the driving forces of land use change. Policy is one of many (yet considered one of the most important) possible driving forces of land use change and therefore there remains much work to be done.

7 CONCLUSIONS AND RECOMMENDATIONS

In this chapter the main research hypothesis is first revisited and, based on findings in the previous chapters, an answer to this hypothesis is formulated. Next it looks again at the challenges in land use modelling (that this thesis aims to make a modest contribution to) and summarises what can be learned from this research project. This chapter ends with an overview of topics related to this thesis that could provide valuable insights in future research.

7.1 Conclusions from this research

In the introduction (chapter 1) the following hypothesis was formulated:
Patterns of land use change concerning residential areas differ between different municipalities in the Netherlands and this is caused by differences in national spatial planning policy for these municipalities.

In order to test the main hypothesis stated above five research questions were posed, to which the research produced the following answers:

What different visions have been dominant in spatial planning since the 1970's concerning housing areas?
In spatial planning, since the 1970's, there are two main types of policy that aim at influencing the location and the amount of residential land use to be realised at given location. On the one hand, there is allocation policy (pro-new residential land use developments) and on the other hand there is restrictive policy (con-new residential land use development). The most important allocation policies that have an influence on the time frame of this study are the Growth-Pole and the VINEX policy. The most prominent restrictive policies are the National Landscapes and the National Ecological Networks. These four policies are further investigated in this study.

What patterns in land use change can be expected the based on the dominant spatial planning policies in the temporal frame of this study?
Based on the four policies stereotypical patterns of residential land use development have been formulated. Growth-Pole policy is expected to result in urban concentration around medium-sized cities in the Netherlands. VINEX policy is expected to result in large-scale but concentrated housing areas close to large and smaller cities. National Landscape policy is expected to cause only minor patches of urban growth in selected municipalities. Areas covered by the National Ecological Network are expected to show hardly any urban development at all.

What metrics can be used to characterise land use patterns for housing areas?
To quantify the observed changes in land use six metrics have been formulated based on literature. These metrics provide insight in patch frequencies, patch frequencies of patches weighted by area and the size and shape of patches.
The Un-weighted Patch Frequency Index describes whether the number of new patches in a municipality is above or below the national average. It is unrelated to the size or shape of the municipality.

This variation on the Area Weighted Patch Frequency Index gives an indication of the relative amount of new patches per unit of area. The Residential Area Weighted Patch Frequency Index is very similar to the Area Weighted Patch Frequency Index, but instead of taking the total area into account it only takes residential area into account. It thus represents the amount of new cells per unit of residential area.

The Indexed Largest Patch Index gives the percentage of the area of a municipality that is covered by the largest patch in the same municipality. The Patch Size Distribution

Index gives an indication of the distribution of patch sizes within the area of analysis. The Area Perimeter Ratio Index gives an indication of the shape of patches by comparing the area of patches by the length of their perimeter.

What patterns of new residential land use can be identified in the study area?
Calculating the metric values provided insight in the patterns of residential land use developments that have taken place in the temporal frame of this research. There is much variation in the frequencies and the size of patches of new residential land use. Overall, the observation is that the patches are unevenly distributed over space. The frequency distributions of the values of all the metrics show a strong skew to the right, indicating that there are many low values and few high values.

What observed differences in patterns of land use change can be related to differences in spatial planning policy?
The expected differences between restrictive (con-housing development) and allocation policies (pro-housing development) are clearly confirmed by the observed values for the metrics. Municipalities with an allocation policy are characterised by a high number of new relatively large residential areas. Where municipalities with allocation policy show high values, the municipalities with restrictive policies show low values and the other way around. These differences between the groups of municipalities with allocation policies and the groups of municipalities with restrictive policies indicate that national planning policy has clearly influenced the development of new residential land use.

There are differences between the groups of municipalities that have allocation policies, but not as clearly as expected. Growth-Pole municipalities show the development of relatively few large patches compared to the VINEX policy, while the opposite was expected. This might have to do with the stage of development the policies are in during the temporal scope of this research. The Growth-Pole policy is older than the VINEX policy. It might be the case that the implementation of an allocation policy starts off with many small developments of residential area and that the larger areas are developed at a later stage. If this is the case, the deviation from the expectation can be explained by the 'age' of the different policies.

When comparing the different restrictive policies it becomes clear that the differences are relatively small. This was also expected as the National Ecological Network and the National Landscape policies are more alike than the allocation policies. In line with the expectations, the National Ecological Network policy turns out to be stricter (and more effective in restraining residential development) than the National Landscapes policy.

The comparison between groups of municipalities with allocation policies or restrictive policies on the one hand and municipalities with neither of these policies on the other hand, clearly shows that policy influences the development of new residential land use. The municipalities with allocation policies show clearly more activity regarding residential development than the municipalities with no specific policy. The municipalities with restrictive policies show clearly less activity. This indicates that policy should definitely be taken into account as driving force for residential land use development. In the previous discussion chapter, however, it was indicated that caution is needed while including policy parameters in land use models that pretend to be able to predict future land use change.
This research has shown that clear differences between different groups of municipalities based on policy can be observed. These observed differences between groups of municipalities suggest that the differences in pattern of residential land use development are caused by differences in policy. However this research has been unable to prove a causal relationship between the policy and patterns of residential land use development.

It is arguable whether policy has similar degrees of impact on all types of land use change. It is expected that the effects of the restrictive policies range beyond residential development only. The allocation policies are more specific and are expected to have less influence on other types of land use change than the type of land use they are allocating.

With regard to the challenges in land use modelling research, briefly introduced in chapter 1, the following observations can be made:

- Modelling the role of institutions: The results of this research clearly show that policy formulated by the national government (being the institution of study) can be clearly quantified when retrospectively analysing patterns of land use change. This indicates that the role of policy by institutions on land use change should be underestimated.
- Understanding temporal dynamics: Temporal dynamics regarding the policies analysed in this research are twofold. The allocation policies show a lag in implementation time after the policy obtained legally binding status. For restrictive policies on the other hand, it turns out to be usual that an area is semi-protected for several years before this is adopted in legally binding policies.
- Feedbacks of land use change on land use: The effects of policy clearly show from the observed patterns of land use change when they are analysed retrospectively. Looking at land use change modelling in a broader sense, this means that transition rule cannot solely depend on observations from the past, as the policy of the past cannot be extrapolated into the future.
- Scale considerations: While analysing the effects of scale on the number of new developments in this study it surfaced that the cell size does not have a clear influenced on the total area of change. This is valid until the cell size becomes so large that the cells no longer capture the objects of analysis because they cannot form a majority in the cell anymore. Noise (errors), shows to decrease with an increase of cell size. The combination of these two findings shows that there is a parabolic curve of cell size effectiveness in which the sweet spot should be sought. Too small cell sizes will result in more errors; too large cell size will be unable to represent the objects of study.
- Multi-scale characteristics of land use systems: The Green Heart case study has shown that the manner in which the metrics have been calculated in this research provide insufficient detail to provide detailed information while analysing a subject using a smaller spatial extent. However, this is not caused by the cell size or the metrics. The cell size should be chosen based on the curve of effectiveness for the object of study and the metrics can be calculated for virtually every spatial scale. The bottleneck in the case study was that the metrics had been calculated per municipality while a calculation per neighbourhood should have been more informative.

7.2 Recommendations for further research

Building on this research, future studies can continue in different directions. Three directions that could provide valuable insights in future research are: driving forces of land use change, methodological challenges and further investigation of the effects of policy on land use change. For these three research directions challenges are summarised.

Challenges concerning the driving forces of land use change closely related to this study include

- the identification of driving forces of land use change other than policy and other frequently investigated driving forces of land use change;
- investigation of the interconnectivity of different driving forces of land use change;
- and research on the causality between the observed land use change and the projected driver of land use change.

Methodological challenges closely related to this study include
- research on if with a what the effect is on results of using a more limited or more elaborated set of metrics than is used in this study;
- the application of the methodology as used in this study on processes that act at other spatial scales;
- and the application of the methodology as used in this study in an attempt to quantify the effects of other driving forces on land use change.

Challenges concerning a further investigation of the effects of spatial planning policy on land use change include
- quantifying the effects of spatial planning policy on land use change using a different methodology (like studying the amount of housing units that have been developed using statistical documents);
- analysis of the social targets of spatial planning policy in stead of just the spatial targets;
- and research on the relations between different political levels in spatial planning and other stakeholders to get a better understanding as policy as a driving force of land use change as a whole.

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Appendix A Topics for further research in Land Use Modelling

#	Topic	Description (if available)	Reference(s)
1	Multi-scale characteristics of land use systems.	It is still unclear to what extent scale dependencies in driving forces are really important. Quantification of the interactions of processes operating at different scales needs to be further researched. Importance of top-down versus bottom up processes and regional dynamics impact on local conditions.	(Verburg, Schot et al., 2004)
2	Scale Considerations / Extent	Processes over different disciplines operate over different spatial scales. Constructing a methodology to represent these processes across scale in one model is a major modelling challenge.	(Parker et al., 2003)
		"The importance of scale and nested, hierarchical approaches cannot be overestimated". No models have been made up till now combining social and ecological processes on a true multiscale level. Fundamental research and modelling paradigms might need to be rethought.	(Agarwal et al., 2002; Heistermann et al., 2006)
		Research is needed to investigate the spatial extent and cell size that are optimal for modelling a certain phenomenon. There might be a curve to be identified representing the performance of a certain modelling techniques for different extents and cell sizes. Using such curve optimal extent and cell size for different modelling techniques might be identified.	(Briassoulis, 2000; Ritsema van Eck & Koomen, 2008; Schrojenstein Lantman, 2008; Seto & Fragkias, 2005)
		Thorough research is needed to examine the scaling behaviour of surface metrics in land use change modelling.	(McGarigal et al., 2009)
3	Temporal Scale issues	Different parameters or phenomena in a model are likely to have different rotation cycles. Due to the set time steps models usually have these different rotation cycles are hard to combine in a single model. Research is needed to identify the relationships of land use changes with different rotation cycles within the context of varying study durations.	(Agarwal et al., 2002; Briassoulis, 2000; Heistermann et al., 2006; Parker et al., 2003; Schrojenstein Lantman, 2008)
4	Thematic Classification	Like spatial and temporal resolution thematic classification is an important consideration concerning the input data of a model. Research is needed to identify a minimum and a maximum number of classes that the input data of a model can have while generating accurate outputs.	(Schrojenstein Lantman, 2008)
5	Building an experimental frame	All spatial data are collected using an experimental frame. This frame includes the boundaries of the study area and the level of abstraction and aggregation of 'real world' phenomena. Challenge is to define an experimental spatial and temporal frame that with the appropriate level of abstraction that captures the driving processes in a model.	(Parker et al., 2003)
6	Understanding Complexity	While Multi Agent Systems / Land Use Cover Change models are an appropriate tool for modelling complexity, theory that defines complexity is still in the development stage.	(Parker et al., 2003)
		If complexity is incorporated in a model this is often on the themes of the modeller(s) specialisation. This can result in a model where complexity is added for human behaviour, but where physical factors are highly generalized or the other way around. If 'complete' complexity is incorporated in the model this is usually done at a set scale level. This neglects the influence that complexity at other spatial or temporal scale levels may have on the modelled phenomenon.	(Agarwal et al., 2002)
7	Individual Decision making	Using bounded rationality for agent decision making results in an almost infinite number of possible formulations of agents. A challenge for researchers designing an agent based model is to decide among a limited number of competing techniques for and theories for decision making. In particular research is needed comparing different decision making theories and techniques and comparing models including these techniques with theory, practice and real world observations.	(Parker et al., 2003)
8	Modelling Institutions	Formal models based on the empirical insights in the roles of institutions have not yet been developed. A challenge is to make formal models incorporating the roles institutions can have on	(Parker et al., 2003)

#	Topic	Description (if available)	Reference(s)
9	Empirical Parameterisation	High resolution, complex models create a challenge for parameterisation and validation. The development for techniques to interpret and understand model output lags behind the development on the tools producing this output.	(Parker et al., 2003)
10	Understanding Temporal Dynamics	Influence of non-linear pathways of change, feedbacks and time-lags deserve more attention in future studies. Availability of data with the appropriate temporal (and spatial) scale is expected to be a major constraint in such research.	(Verburg, Schot et al., 2004)
11	Quantifying Neighbourhood effects.	The theoretical basis of the quantification of neighbourhood functions for the cellular automata is still poor. Besides the usual relations based on expert knowledge it is recommended that a more sophisticated and reproducible methodology is developed to define these neighbourhood effects. At the same time, a balance must be achieved between neighbourhood effects that are caused by interactions between neighbouring land use cells and effects that are caused by spatial autocorrelation.	(Verburg, Schot et al., 2004)
12	Methodological intergration	Techniques and methods developed in very different disciplines might help to develop better simulation algorithms.	(Verburg, Schot et al., 2004)
13	Feedback of land use change on land use	Further assessment of the effects of land use and land cover change and their feedbacks on future land use and land cover.	(Verburg, Schot et al., 2004)
		Land use can not only be seen as a driver, but also as a result of more fundamental social and ecological patters ad processes.	(Agarwal et al., 2002)
14	Feedbacks society and environment		(Heistermann et al., 2006)
15	Urban - Rural interactions	At this moment few models incorporate urban – rural interactions. Large impacts of these interactions are expected in developed countries through the emerge of multi-functional hinterlands of cities and in countries in development where unequal development between urban and rural areas and food security are important issues.	(Verburg, Schot et al., 2004)
16	The use of theories and models in land use decision making		(Briassoulis, 2000)
17	The relationship between theories and models of land use change		(Briassoulis, 2000)
18	Better understanding of the interaction between land cover, land use and function	Further characterization of land functions is needed because of the importance of goods and services that are not directly related to the specific intend of the land management.	(Verburg et al., 2009)
19	Methods to map land use and land function	The increasing attention for the multifunctionality of land requires the development of methods and tools to map and quantify the different functions across the landscape. Methods based on the research on land cover are clearly insufficient when multiple functions of the land are considered.	(Verburg et al., 2009)
20	Open Source approach to modelling	Based on the Linux principle: When enough people take a look at something, all problems will be identified (and hopefully tackled) someday. Agarwal et al. propose the development of open source modular models.	(Agarwal et al., 2002)

Appendix B Metrics to quantify Land Use Change

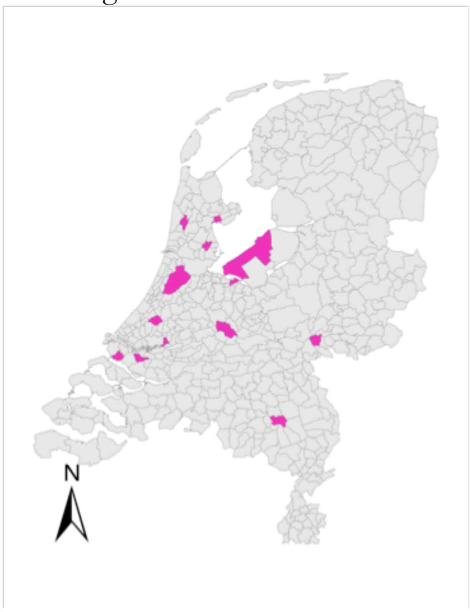
Metric	Description (if available)	Reference (s)
Aggregation index (AI	The number of like adjacencies involving the corresponding class, divided by the maximum possible number of like adjacencies involving the corresponding class, which is achieved when the class is maximally clumped into a single, compact patch; multiplied by 100 (to convert to a percentage).	(McGarigal et al., 2009)
Area-weighted mean patch fractal dimension	Describes the degree to which the shape of an urban area is irregular or complex.	(Seto & Fragkias, 2005)
Circularity ratio	This metric indicates how much a shape deviates from its most compact form, a circle	(Ritsema van Eck & Koomen, 2008)
Concentration within an area	Useful for densities in urban areas for analysing urban sprawl	(Ritsema van Eck & Koomen, 2008)
Concentrations formed by a set of contiguous areas	To analyze the size and shape of individual constellations of a certain class	(Ritsema van Eck & Koomen, 2008)
Concentrations formed by proximity between a set of areas	To analyze the dispersion of certain classes	(Ritsema van Eck & Koomen, 2008)
Contagion	The observed contagion over the maximum possible contagion for the given number of patch types.	(Gustafson, 1998; McGarigal et al., 2009)
Contiguity	Contiguity index assesses the spatial connectedness, or contiguity, of cells within a grid-cell patch to provide an index of patch boundary configuration and thus patch shape. Also the mean contiguity index, area-weighted contiguity index and the coefficient of variation in the contiguity index are used.	(Gustafson, 1998; McGarigal et al., 2009)
Contrast measures on neighbourhood patches	The degree of contrast between neighbouring patches	(Gustafson, 1998)
Contrast-weighted edge density	The sum of the lengths (m) of each edge segment involving the corresponding patch type multiplied by the corresponding contrast weight, divided by the total landscape area (m2), multiplied by 10,000 (to convert to hectares).	(McGarigal et al., 2009)
Core area	Core area is the portion of a patch that is further than some specified distance from an edge and presumably not influenced by edge effects.	(Gustafson, 1998; McGarigal et al., 2009)
Density of patches	the number of patches of the corresponding patch type (NP) divided by total landscape area, multiplied by 10,000 and 100 (to convert to 100 hectares)	(Gustafson, 1998; McGarigal et al., 2009)
Edge density	the sum of the lengths (m) of all edge segments in the landscape, divided by the total landscape area (m2), multiplied by 10,000 (to convert to hectares).	(McGarigal et al., 2009; Seto & Fragkias, 2005)
Elongation and deformity indices		(Gustafson, 1998)
Enrichment Factor	Represents the over / under representation of certain types of patch classes	(Verburg et al., 2004)
Frequency of specific patch adjacencies	Frequency in which certain land use class patches are adjacent	(Gustafson, 1998)
GISFrag	GISFrag is an index that calculates the average distance to the nearest edge of all the pixels of the class of interest.	(Gustafson, 1998)
Interspersion and juxtaposition index	Extent to which patch types are interspersed	(Gustafson, 1998)
Lacunarity analysis (pixel based)	A multi-scale method used to determine the heterogeneity of a system property represented as a binary response in one, two or three dimensions.	(Gustafson, 1998)
Largest patch index	The area (m2) of the largest patch in the landscape divided by total landscape area (m2), multiplied by 100 (to convert to a percentage); in other words, LPI equals the percent of the landscape that the largest patch comprises.	(McGarigal et al., 2009)
Linearity index	-	(Gustafson, 1998)
Mean Euclidean nearest neighbour distance	The distance (m) to the nearest neighbouring patch of the same type, based on shortest edge-to-edge distance. Also The Area-Weighted Euclidian nearest neighbour distance and the coefficient of variation in the Euclidian nearest neighbour distance are used	(McGarigal et al., 2009)

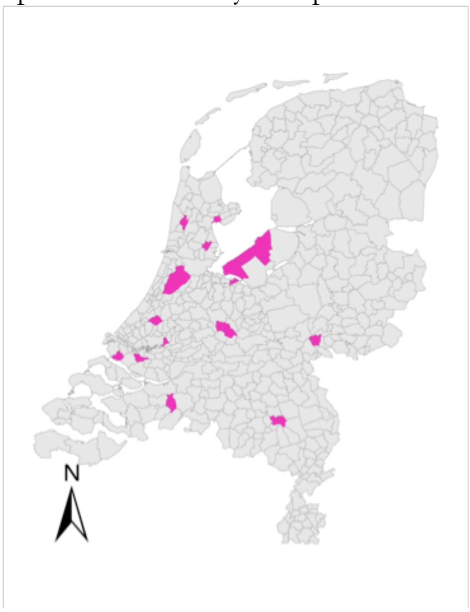
Metric	Description (if available)	Reference (s)
Mean patch shape index	The patch perimeter (given in number of cell surfaces) divided by the minimum perimeter (given in number of cell surfaces) possible for a maximally compact patch (in a square raster format) of the corresponding patch area.	(McGarigal et al., 2009)
Number of patches	The number of patches of a certain land use class	(Gustafson, 1998; Seto & Fragkias, 2005)
Patch Cohesion	To quantify the connectivity of habitat as perceived by organisms dispersing in binary landscapes.	(Gustafson, 1998)
Patch richness density	The number of different patch types present within the landscape boundary.	(McGarigal et al., 2009)
Patch size	Equals the area (m2) of the patch, divided by 10,000 (to convert to hectares). Also described are the mean patch area and the coefficient of variation of the patch area.	(Gustafson, 1998; McGarigal et al., 2009; Seto & Fragkias, 2005)
Patch size distribution	The distribution of patch sizes for a certain land use class	(Ritsema van Eck & Koomen, 2008)
Patch statistics	Patch characteristics of an entire landscape can be reported as a statistical summary. This can be the mean, median, variance and frequency distribution for all patches of a certain class.	(Gustafson, 1998)
Perimeter / area ratio	The ratio between the area and the edge length of a patch or group of patches	(Gustafson, 1998; Ritsema van Eck & Koomen, 2008)
Perimeter of all patches in a class	The edge length of all patches of a certain land use class	(Gustafson, 1998)
Perimeter of individual patch	The edge length of a single patch of a certain land use class	(Gustafson, 1998)
Radius of gyration	Equals the mean distance (m) between each cell in the patch and the patch centroid. Also the mean radius of gyration and the coeficient in variation of the radius of gyration are mentioned.	(Gustafson, 1998; McGarigal et al., 2009)
Shape membership function	This metric is more elaborated than the circularity ratio. It is also shape and size independent and has the additional advantage of quantitatively describing a number of shapes	(Ritsema van Eck & Koomen, 2008)
Simpson's diversity index S	Indicates the probability that two different random locations within a raster cell have different land use types	(McGarigal et al., 2009; Ritsema van Eck & Koomen, 2008)
Simpson's evenness index	The observed Simpson's Diversity Index divided by the maximum Simpson's Diversity Index for that number of patch types. Note, Pi is based on total landscape area (A) excluding any internal background present.	(McGarigal et al., 2009)
The dominance pmax	The proportion of the largest function within a raster cell.	(Ritsema van Eck & Koomen, 2008)
The entropy H	Ranges from 0 to ln m. Indicates the diversity of land use types within a single cell	(Ritsema van Eck & Koomen, 2008)
The species richness m	In this case the number of land use classes in a single cell. This ranges from 1 to n where n is the total number of land use classes.	(Ritsema van Eck & Koomen, 2008)
Total edge contrast index	The sum of the lengths (m) of each edge segment involving the corresponding patch type multiplied by the corresponding contrast weight, divided by the sum of the lengths (m) of all edge segments involving the same type, multiplied by 100 (to convert to a percentage).	(McGarigal et al., 2009)
Urbanisation degree	The percentage of the total surface that is considered to be urbanised	(Ritsema van Eck & Koomen, 2008)

Appendix C List of Growth-Pole municipalities

Social and Cultural Planning bureau	Wikipedia
Alkmaar	Alkmaar
Almere	Almere
Capelle aan den IJssel	Capelle aan den IJssel
Duiven	Duiven
-	Etten-Leur
Haarlemmermeer	Haarlemmermeer
Hellevoetsluis	Hellevoetsluis
Helmond	Helmond
Hoorn	Hoorn
Houten	Houten
Huizen	Huizen
Lelystad	Lelystad
Nieuwegein	Nieuwegein
Purmerend	Purmerend
Spijkenisse	Spijkenisse
Westervoort	Westervoort
Zoetermeer	Zoetermeer
16 Municipalities	17 Municipalities

Maps of the Growth-Pole Municipalities; municipalities as listed by the Social and Cultural Planning bureau on the left and municipalities as listed by Wikipedia on the right.



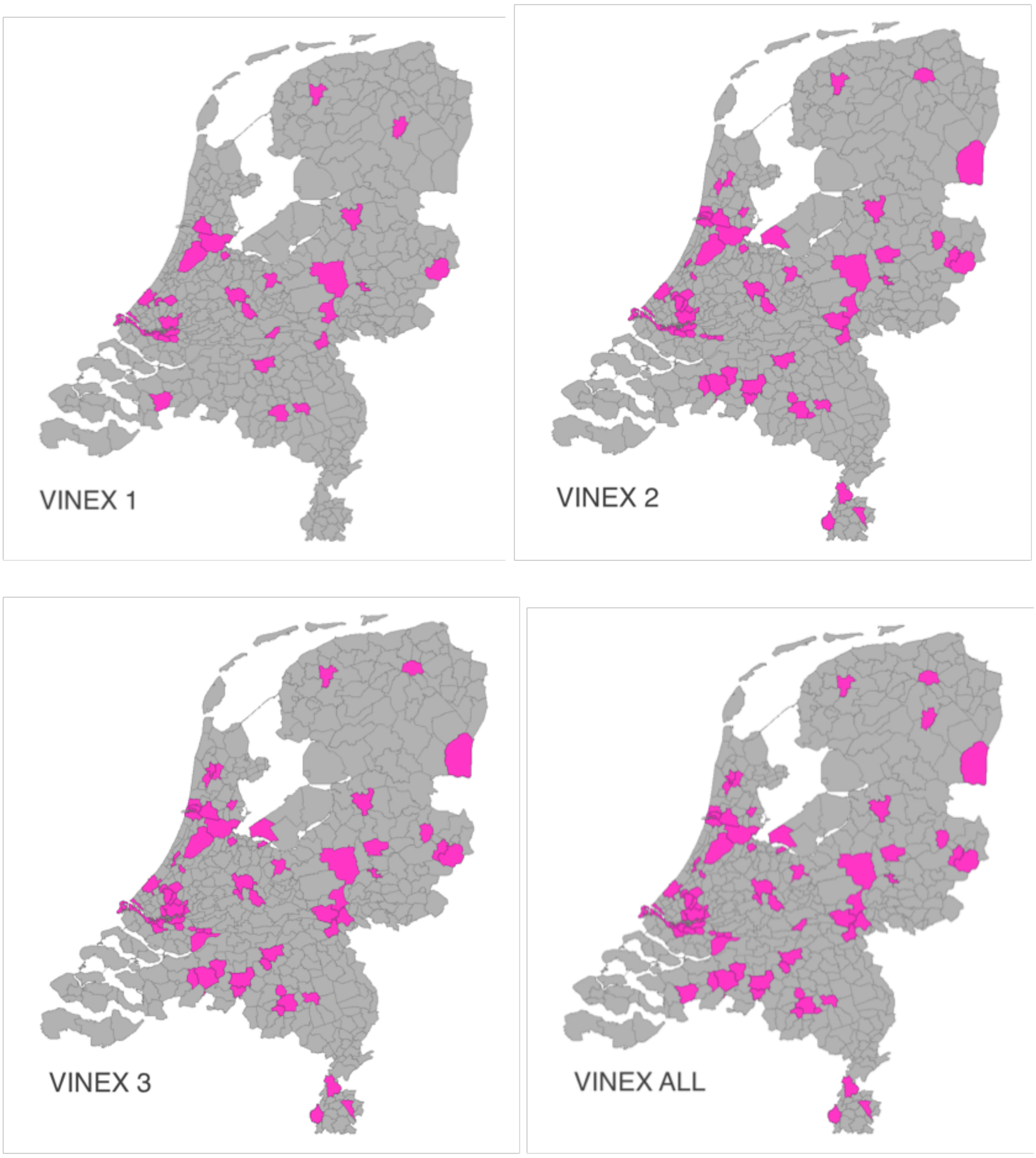


Appendix D List of VINEX municipalities

VINEX-Location	Municipality	wp*	rivm**	vrom***
Portland	Albrandswaard / Barendrecht	X	X	
Vroonermeer	Alkmaar		X	X
Almelo-Noord	Almelo		X	
Almelo-Oost	Almelo		X	
Almelo-West	Almelo		X	
Nijrees	Almelo			X
Almere Buiten	Almere		X	X
Almere Poort	Almere		X	X
Almere Stad	Almere		X	X
Nieuwland	Amersfoort	X	X	X
Vathorst	Amersfoort	X	X	X
IJburg	Amsterdam	X	X	X
De Akker	Amsterdam		X	X
Woudhuis	Apeldoorn	X	X	X
Osseveld	Apeldoorn	X		X
Zuidbroek (in construction phase)	Apeldoorn	X	X	X
Schuytgraaf	Arnhem	X	X	
Stadsblokken	Arnhem			X
Driel-Oost	Arnhem			X
Kloosterveen	Assen	X		
Carnisselande	Barendrecht	X		X
Noordrand II	Bergschenhoek		X	X
Noordrand III	Berkel en Rodenrijs		X	X
Heivelden / Heuveleind	Best		X	X
Broekpolder	Beverwijk		X	X
Kroeten	Breda		X	
IJpelaar / Nieuw-Wolfshaar	Breda		X	X
Breda-Noordoost / Teteringen	Breda		X	X
Bavel-Dorst	Breda		X	
Westerpark	Breda			
Haagse Beemden	Breda			
s-Gravenland	Capelle aan den Ijssel			X
De Groote Wielen	Den Bosch	X	X	
Haverleij	Den Bosch	X	X	
Empel Noord en Zuid	Den Bosch		X	X
Hoogveld II / Engelen	Den Bosch			X
Wateringse Veld	Den Haag	X	X	X
Leidschenveen	Den Haag	X	X	X
Made en Uithofspolder	Den Haag	X		
Ypenburg	Den Haag / Pijnacker-Nootdorp	X	X	X
De Vijfhoek	Deventer		X	X
Buitenstad	Dordrecht			X
Oudelandshoek	Dordrecht			X
Meerhoven	Eindhoven	X	X	
Blixembosch	Eindhoven		X	X
Delftlanden	Emmen		X	X
De Eschmarke	Enschede	X	X	X
De Keen / Schoenmakershoek	Etten-Leur		X	
Etten-Leur-Noord	Etten-Leur			X
Gijzenrooi	Geldrop		X	
Boskens	Goirle		X	
Bakertand	Goirle		X	X
De Blauwe Stad	Groningen		X	
De Held	Groningen		X	X
Reitdiep	Groningen		X	
Floriande	Haarlemmermeer	X	X	
Toolenburg-Zuid	Haarlemmermeer	X		X
IJ-landen	Haarlemmermeer			X
Nieuw-Vennep-West	Haarlemmermeer			X
Getsewoud	Haarlemmermeer	X		
Waterakkers-Lunetten	Heemskerk		X	X
Oostertocht	Heerhugowaard		X	
Stad van de Zon	Heerhugowaard		X	X
Hoogveld-Heerlerbaan	Heerlen		X	X

VINEX-Location	Municipality	wp*	rivm**	vrom***
Brandevoort	Helmond	X	X	X
Dierdonk	Helmond	X		X
Suytkade	Helmond	X		
Lungendonk (in planning phase)	Helmond	X		
De Volgerlanden	Hendrik Ido Ambacht		X	X
Vossenbelt	Hengelo		X	X
Houten-Zuid	Houten	X	X	X
Vierde Kwadrant	Huizen			X
Zenderpark	IJsselstijn			X
Bruggesloot	Langedijk			X
Zuiderburen, Hempens-Teems	Leeuwarden	X	X	X
Roomburg	Leiderdorp		X	
Leyhof	Leiderdorp			X
Bemmel	Lingewaard			X
Caberg-Lanakerveld	Maastricht		X	X
Amby-Zuid	Maastricht			X
Hazendans	Maastricht			X
Waalsprong	Nijmegen	X	X	X
Broek en Simontjespolder	Oegstgeest			X
Vlinderbuurt	Oosterhout		X	
Vrachelen II	Oosterhout			X
Westeraarn	Overbetuwe		X	X
Oostpolder	Papendrecht		X	X
Pijnacker-Zuid	Pijnacker		X	X
Emerald-Delfgauw	Pijnacker		X	X
Weidevenne	Purmerend		X	X
Weihoek	Roosendaal	X		
Nesselande	Rotterdam	X	X	X
Spaland-Oost	Schiedam			X
Hoogveld	Sittard-Geleen		X	X
Sittard-West	Sittard-Geleen		X	
Baanhoek-West	Sliedrecht		X	X
Maaswijk II	Spijkenisse			X
Passewaaij	Tiel	X		
Reeshof / De Wijk	Tilburg		X	X
Nieuwe Warande	Tilburg		X	
Leidsche Rijn	Utrecht	X	X	X
Meerhoven	Veldhoven			X
Velserbroek	Velsen		X	X
Voorhout-Noord	Voorhout (since 2006 Teylingen)		X	X
Hoogh Teylingen	Voorhout (since 2006 Teylingen)		X	X
Hoeveneesstraat	Vught			X
Saendelft	Zaanstad	X	X	X
Willis	Zaanstad			X
Oosterheem	Zoetermeer	X	X	X
Noord-Oost	Tilburg			X
Leesten	Zutphen	X	X	X
Stadshagen	Zwolle	X	X	X
*Mentioned by Wikipedia (Wikipedia contributors 2009b) **Mentioned by RIVM (Lörzing et al. 2006) ***Mentioned by VROM (BIJN)				

Location of municipalities with VINEX locations in the Netherlands



VINEX 1: 24 municipalities mentioned by Wikipedia (Wikipedia contributors 2009b)
VINEX 2: 51 municipalities mentioned by RIVM (Lörzing et al. 2006)
VINEX 3: 61 municipalities mentioned by VROM (BIJN, 2009)
VINEX ALL: 66 municipalities, combination of VINEX 1, 2 and 3.

Appendix E Script for prototype calculation procedure

```
# ---------------------------------------------------------------------------
# Land Use Compare -- by Niels van der Vaart -- 23 October 2009
# ---------------------------------------------------------------------------


# Import system modules
import sys, string, os, csv, threading, thread, time, shutil
from statlib import stats
try:
    import arcgisscripting
except ImportError:
    import win32com.client
    class arcgisscripting(object):
        @staticmethod
        def create():
            return win32com.client.Dispatch('esriGeoprocessing.GpDispatch.1')


# ArcGIS stuff
gp = arcgisscripting.create()
gp.CheckOutExtension("Spatial")
gp.AddToolbox("C:/Program Files/ArcGIS/ArcToolbox/Toolboxes/Data Management Tools.tbx")
gp.AddToolbox("C:/Program Files/ArcGIS/ArcToolbox/Toolboxes/Analysis Tools.tbx")
gp.AddToolbox("C:/Program Files/ArcGIS/ArcToolbox/Toolboxes/Spatial Analyst Tools.tbx")
gp.AddToolbox("C:/Program Files/ArcGIS/ArcToolbox/Toolboxes/Spatial Statistics Tools.tbx")
gp.AddToolbox("C:/Program Files/ArcGIS/ArcToolbox/Toolboxes/Conversion Tools.tbx")


# Functions
## Function that lists files in a folder with a certain file extension with complete path
## Input data: Folder containing the files and file extension
def ListFilesFolder(Folder, FileExt):
    ## Makes a list of all files in a directory
    DirList = os.listdir(Folder)
    ##Makes an empty list for the files with the chosen extension
    FileList = []
    ## Walks the directory list
    for x in DirList:
        ## Checks if the entries end with the chosen extension
        if x.endswith(FileExt):
            ## If the extension is right file is added to the list
            FileList.append(str(Folder)+str(x))
    ## Deletes the DirList
    del DirList
    ## Returns the file list
    return FileList


## Function that lists files in a folder with a certain file extension without path
## Input data: Folder containing the files and file extension
def ListFiles(Folder, FileExt):
   ## Makes a list of all files in a directory
    DirList = os.listdir(Folder)
    ##Makes an empty list for the files with the chosen extension
    FileList = []
    ## Walks the directory list
    for x in DirList:
        ## Checks if the entries end with the chosen extension
        if x.endswith(FileExt):
            ## If the extension is right file is added to the list
           FileList.append(str(x))
    ## Deletes the DirList
    del DirList
    ## Returns the file list
    return FileList


## Function that copies files from one dir to another
## Input data: Source directory and destination directory
def CopyFiles(Source, Destination):
    ## Checks if the destination path exists
    if os.path.exists(Destination) == False:
        ## if not makes the destination folder
        os.mkdir(Destination)
    ## Changes directory to the source
    os.chdir(Source)
    ## Makes a list of all datasets in the source
    DataList = os.listdir(Source)
    ## Iterates through the source data list
    for Data in DataList:
        ## If the source dataset does not exists in the destination folder
        if os.path.exists(str(Destination)+str(Data)) == False:
            ## The file is copied to the destination
            shutil.copy(Data, Destination)
    ## The datalist is deleted
    del DataList


## Function that makes an (output) directory
## Input data: Name of the new dir
def MakeOutDir(DirName):
    ## Checks if the dir to be made exists
    if os.path.exists(str(ws)+str(DirName)+"\\") == False:
        ## If not makes the new dir
        os.mkdir(str(ws)+str(DirName)+"\\")
    ## makes a variable of the new dir
    Dir = str(ws)+str(DirName)+"\\"
    ## Returns the new dir as a variable
    return Dir


## ArcGIS wants strange names for the field type when adding a field. Here a transformation.
```

```
## Input data: Field Type as output of gp.listfields.type
def TransformFieldType(FieldType):
    ## Make sure vatiable is string and in CAPITALS
    FieldType = str(FieldType).upper()
    ## Here goes the conversion
    if FieldType == "STRING":
        ## If it is "STRING" make it "TEXT"
        TransformedFieldType = "TEXT"
    elif FieldType == "SMALLINTEGER":
        ## If it is "SMALLINTEGER" make it "SHORT"
        TransformedFieldType = "SHORT"
    elif FieldType == "INTEGER":
        ## If it is "INTEGER" make it "LONG"
        TransformedFieldType = "LONG"
    else:
        ## Else, leave it as it is...
        TransformedFieldType = FieldType
    ## Unbinds references
    del FieldType
    ## Returns transformed field type
    return TransformedFieldType


## Function to transpose a matrix
## Input data: Matrix to be transposed (list containing lists)
def transpose(matrix):
    ## Returns transposed matrix
    return [[matrix[x][y] for x in range(len(matrix))] for y in range(len(matrix[0]))]


## Function that donates all fields from one feature to another
## Input data: Donor Feature Class and Donee Feature Class
def DonateFields(DonorFC, DoneeFC):
    ## Makes a list of the fields in the Input Feature
    fld = gp.listfields(DonorFC)
    ## Skip the header field
    fldn = fld.next()
    ## Skip the FID field
    fldn = fld.next()
    ## Skip the SHAPE field
    fldn = fld.next()
    ## Insert a search cursor to extract values
    scurD = gp.searchcursor(DonorFC)
    ## Jumps to the first row
    srowD = scurD.next()
    ## number to prevent duplicate field names
    num = 1
    ## As long as there is a field do following
    while fldn:
        ## Determine the new field name of 10 chars
        NewField = str(fldn.name[0:4])+"_"+str(num)+"_cp"
        ## Field type
        FieldType = str(fldn.type)
        ## Transform the ArcGIS Field output to a usable format
        #print FieldType
        FieldType = TransformFieldType(FieldType)
        #print FieldType
        if FieldType != "TEXT":
            ## Add a field with the same type and name + _cp to the Input Feature
            gp.AddField_management(DoneeFC, NewField, FieldType, "", "", "", "", "NULLABLE", "NON_REQUIRED", "")
            ## Determine field value
            Value = srowD.getvalue(fldn.name)
            ## Copy the original value into the field
            gp.CalculateField_management(DoneeFC, NewField, Value, "VB", "")
        ## Hop to the next field
        fldn = fld.next()
        ## Incremnent in number by one
        num = num + 1
        del NewField, FieldType
    ## Unbind all references
    del DonorFC, DoneeFC, fld, fldn, scurD, srowD, num, Value


## Function to recursively clip a file by all the features in another file
## Input data: Clip Feature, Input feature to be clipped, year of input feature (yyyy)
## and copy (1 = yes or 0 = no). If copy = y, all fields are copied from Clip Feature
## to Input Feature after clipping.
def RecursiveClip(ClipData, Input, year, copy):
    ## Makes a folder to write results to
    OutDir = MakeOutDir("clips")
    ## Makes a list of all fields in the clip data
    FieldList = gp.listfields(ClipData)
    ## Goes to the first field
    Field = FieldList.Next()
    ## Assigns the name of the first field to variable
    FieldName = Field.Name
    ## Inserts a geoprocessing search cursor in the table of the clip data
    scur = gp.searchcursor(ClipData,"","","","")
    ## Brings the search cursor to the first record in the clip data table
    srow = scur.Next()
    ## Sets numbering for clip features to 1
    ClipNum = 1
    # 2 operations below were in while clause at first!!!
    ## Makes name for clip feature layer based on the year
    ClipLayer = "Clip_Layer"+str(year)
    ## Makes a feature layer from the cliup data with the ClipLayer name
    gp.MakeFeatureLayer_management(ClipData, ClipLayer, "", "", "")
    ## As long as there is a row in the clip feature execute following
    while srow:
        if ClipNum > -1:
            ## Get value from the first field in the clip data table
            Value = srow.getvalue(FieldName)
            ## Select a feature from the ClipLayer based on the current value of the first field
            gp.SelectLayerByAttribute_management(ClipLayer, "NEW_SELECTION", str(FieldName)+"="+str(Value))
            ## Makes an output file name formatted: Clip_###_yyyy.shp
            Output = str(OutDir)+"Clip_"+str("%(#)03d" % {'#' : ClipNum})+"_"+str(year)+".shp"
            ## Clips the input data by the selection of the clip layer
            gp.Clip_analysis(Input, ClipLayer, Output, "")
            ## If the fields are supposed to be copied
```

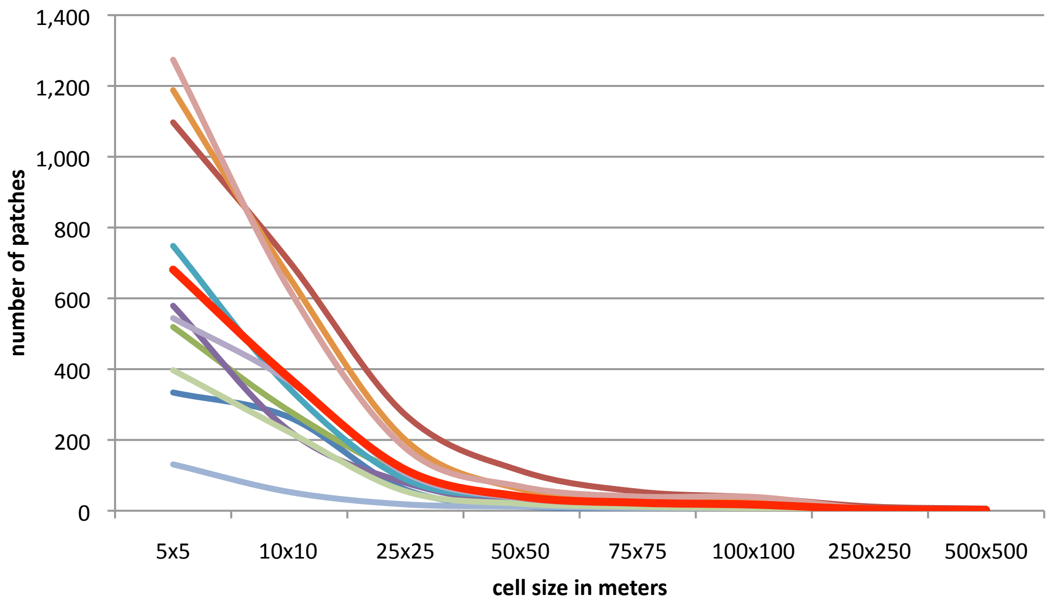
```
                if copy == 1:
                    ## Copy the fields to the clipped datasets
                    DonateFields(ClipLayer, Output)
                ## Undoes the selection in the ClipLayer
                gp.SelectLayerByAttribute_management(ClipLayer, "CLEAR_SELECTION", "")
                ## Goes to the next row in the clip data
                del Value, Output
            print str(ClipNum)+"_clipped"
                ## Increments the clip number by 1
            srow = scur.Next()
            ClipNum = ClipNum + 1
        ## Unbind all references
        del ClipData, Input, year, FieldList, Field, FieldName, scur, srow, ClipNum, ClipLayer


    ## Function to rasterize polygons
    ## Input data: Input Feature, field to base raster on and cell size for the raster
    def Rasterize(InFeature, Field, CellSize):
        ## Makes a folder to write results to
        OutDir = MakeOutDir("rasters")
        ## Makes a name for the out feature
        OutFeature =  str(OutDir)+str(InFeature[0:13])
        ## Do polygon to raster operation
        gp.PolygonToRaster_conversion(InFeature, Field, OutFeature, "MAXIMUM_COMBINED_AREA", "NONE", CellSize)
        ## Unbind all references
        del OutDir, OutFeature


    ## Function that compares rasters using map algebra
    ## Input data: New Raster, Old Raster and value to be compared
    def MapAlgebraCompare(InRasNew, InRasOld, Value):
        ## Makes a folder to write results to
        OutDir = MakeOutDir("mapalgebra")
        ## Makes a name for the output dataset
        OutRas = str(OutDir)+str(InRasNew[0:8])+"_diff"
        ## Makes variable for the input datasets
        Input =  str(ws)+"rasters\\"+str(InRasNew)+";"+str(ws)+"rasters\\"+str(InRasOld)
        ## Does the map algebra
        gp.SingleOutputMapAlgebra_sa("CON(("+str(InRasNew)+"    ==    "+str(Value)+"    AND    "+str(InRasOld)+"    <>
"+str(Value)+ "), 1, 0)", OutRas, Input)
        ## Unbind all references
        del OutDir, OutRas, Input


    ## Function to polygonize rasters
    ## Input data: Input Raster and value to group upon
    def Polygonize(InRas, Value):
        ## Makes a folder to write results to
        OutDir = MakeOutDir("polydiff")
        ## Makes a name for the output dataset
        OutPoly = str(OutDir)+str(InRas)
        ## Convert the rasters to polygons
        gp.RasterToPolygon_conversion(InRas, OutPoly, "NO_SIMPLIFY", str(Value))
        ## Unbind all references
        del OutDir, OutPoly


    ## Function that calculates areas of polygons
    ## Input data: Polygon dataset
    def CalcArea(InPoly):
        ## Makes a folder to write results to
        OutDir = MakeOutDir("polyarea")
        ## Makes a name for the output dataset
        OutPoly = str(OutDir)+str(InPoly)
        ## Calculate the ara of the polygons
        gp.CalculateAreas_stats(InPoly, OutPoly)
        ## Unbind all references
        del OutDir, OutPoly



    #Script
    ## Bind all variables
    ws = "C:\\cellsize\\10\\"
    gp.Workspace = ws
    gp.OverwriteOutput = 1
    SourceData = str(ws)+"src\\"
    WorkingData = str(ws)+"data\\"
    Muni = str(WorkingData)+"muni2003.shp"
    BS1993 = str(WorkingData)+"1993.shp"
    BS2003 = str(WorkingData)+"2003.shp"
    CellSize = 10
    CSV = "values.csv"


    print "Starting Script"


    ## Copy a clean dataset
    CopyFiles(SourceData, WorkingData)

    print "Copying done"


    ## Make clips of the land use datasets
    RecursiveClip(Muni, BS1993, 1993, 1)
    RecursiveClip(Muni, BS2003, 2003, 1)

    print "Clipping done"


    ## Rasterize the clips
    Clips = str(ws)+"clips\\"
    ShapeList = ListFiles(Clips, "shp")
    os.chdir(Clips)
    for Shape in ShapeList:
        Rasterize(Shape, "CODE", CellSize)

    print "Rasterizing done"
```

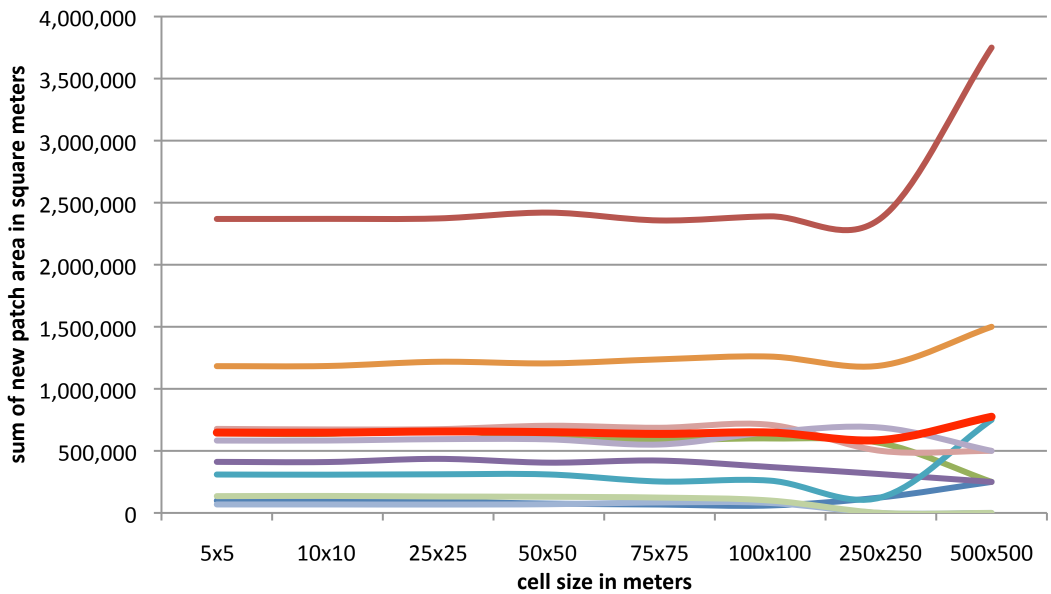
```
## Compare the rasters using map algebra
gp.workspace = str(ws)+"rasters\\"
rasters = gp.ListRasters("", "")
raster = rasters.next()
while raster:
    InRasOld = raster
    raster = rasters.next()
    InRasNew = raster
    raster = rasters.next()
    MapAlgebraCompare(InRasNew, InRasOld,  99)

print "Map Algebra done"


## Poligonize the map algebra output
gp.workspace = str(ws)+"mapalgebra\\"
rasters = gp.ListRasters("", "")
raster = rasters.next()
while raster:
    Polygonize(raster, 1)
    raster = rasters.next()

print "Polygonizing done"


## Calculate the area's
gp.workspace = str(ws)+"polydiff\\"
features = gp.ListFeatureClasses("", "")
feature = features.next()
while feature:
    FeatureLayer = str(feature)+"_Layer"
    gp.MakeFeatureLayer_management(feature, FeatureLayer, "", "", "")
    gp.SelectLayerByAttribute_management(FeatureLayer, "NEW_SELECTION","GRIDCODE = 1")
    try:
        CalcArea(FeatureLayer)
    except:
        print " -- No changes in this municipality ("+str(FeatureLayer)+")at the chosen resolution"
    gp.SelectLayerByAttribute_management(FeatureLayer, "CLEAR_SELECTION", "")
    feature = features.next()

print "Calculating areas done"


## Write the area's to a CSV file
SuperList = []
path = str(ws)+"polyarea\\"
gp.workspace = path
ds = gp.ListFeatureClasses()
dsn = ds.Next()
while dsn:
    FilePath = str(path)+str(dsn)
    flist = gp.ListFields(FilePath)
    fn = flist.Next()
    while fn:
        if fn.Name == "F_AREA":
            FieldName = fn.Name
            List = [dsn]
            scur = gp.searchcursor(FilePath,"","","","")
            srow = scur.Next()
            while srow:
                val = srow.getvalue(FieldName)
                List.append(val)
                srow = scur.Next()
            SuperList.append(List)
        fn = flist.Next()
    dsn = ds.Next()

SuperList2 = []
header = []
StatsList = ["muni","len","sum","mean","stdev"]
for x in StatsList:
    header.append(x)
SuperList2.append(header)
for x in SuperList:
    values = []
    values.append(x[0])
    values.append(len(x[1:]))
    values.append(stats.sum(x[1:]))
    values.append(stats.mean(x[1:]))
    try:
        values.append(stats.stdev(x[1:]))
    except:
        print "Error calculating the standard deviation"
        values.append("")
    SuperList2.append(values)

SuperList3 = []
path = str(ws)+"clips\\"
gp.workspace = path
ds = gp.ListFeatureClasses()
dsn = ds.Next()
FilePath = str(path)+str(dsn)
flist = gp.ListFields(FilePath)
fn = flist.Next()
header = []
header.append("File")
while fn:
    header.append(fn.Name)
    fn = flist.Next()
SuperList3.append(header)
while dsn:
    FilePath = str(path)+str(dsn)
    flist = gp.ListFields(dsn)
    fn = flist.Next()
    values = []
    values.append(dsn)
    while fn:
```

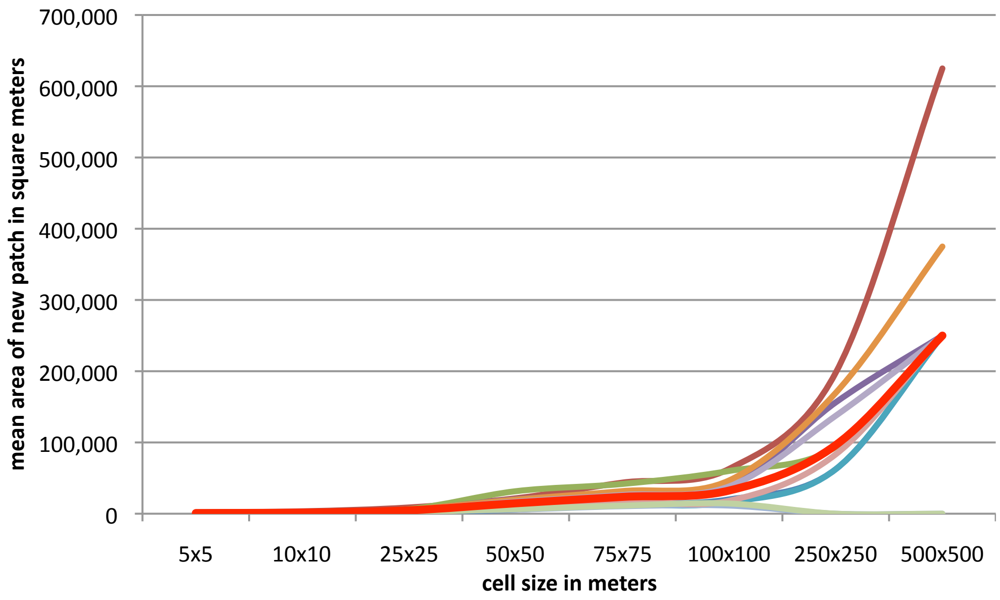
```
        FieldName = fn.Name
        scur = gp.searchcursor(FilePath,"","","","")
        srow = scur.Next()
        val = srow.getvalue(FieldName)
        values.append(val)
        fn = flist.Next()
    SuperList3.append(values)
    dsn = ds.Next()
    dsn = ds.Next()

Leng = len(SuperList2)
SuperList4 = []
header = []
for x in SuperList2[0]:
    header.append(x)
for x in SuperList3[0]:
    header.append(x)
SuperList4.append(header)
n1 = 1
n2 = 1
while n1 < Leng:
    sublist = []
    for x in SuperList2[n1]:
        sublist.append(x)
    while SuperList3[n2][0][5:8] != SuperList2[n1][0][5:8]:
        print str(SuperList3[n2][0][5:8])+" has no statistics"
        n2 = n2 + 1
    for x in SuperList3[n2]:
        sublist.append(x)
    SuperList4.append(sublist)
    n1 = n1 + 1
    n2 = n2 + 1

f = file(r""+str(ws)+str(CSV)+"","wb")
w = csv.writer(f, dialect="excel")
w.writerows(SuperList4)
f.close()

print "Writing to CSV done"


print "Script Finished"
```

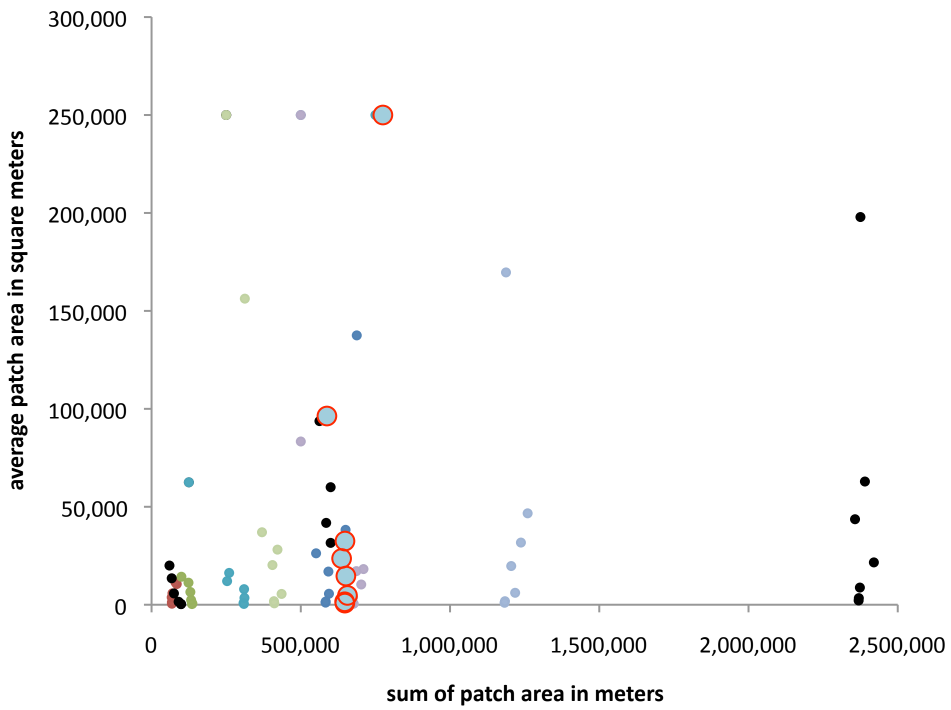
Appendix F Effects of cell size on the prototype calculation

To get an insight of the effects of cell size on the number and size of patches that come out of the calculation three graphs and one scatter diagram have been plotted. These plots contain the observed values for the ten selected test municipalities. In the graphs the number of patches, the sum of patch area and the average patch area are plotted against the different cell sizes. In the scatter diagram the average patch area is plotted against the total sum of patch area. Each dot represents a cell size (overall, higher cell size means higher average patch size) and each colour represents a test case. In all graphs the bold red line or bold red dots represent the average values for the test municipalities.






700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
mean area of new patch in square meters
5x5
10x10
25x25
50x50
75x75
100x100
250x250
500x500
cell size in meters


300,000
250,000
200,000
150,000
100,000
50,000
0
average patch area in square meters
0
500,000
1,000,000
1,500,000
2,000,000
2,500,000
sum of patch area in meters

Appendix G Script for refined calculation procedure

```
# ---------------------------------------------------------------------#
# New Housing Statistics -- by Niels van der Vaart -- 13 January 2010   #
# ---------------------------------------------------------------------#


###### Preperations:

## Import system modules
import sys, string, os, csv, shutil
from statlib import stats
import arcgisscripting

## ArcGIS stuff
gp = arcgisscripting.create(9.3)
gp.CheckOutExtension("Spatial")
gp.AddToolbox("C:/Program Files/ArcGIS/ArcToolbox/Toolboxes/Data Management Tools.tbx")
gp.AddToolbox("C:/Program Files/ArcGIS/ArcToolbox/Toolboxes/Analysis Tools.tbx")
gp.AddToolbox("C:/Program Files/ArcGIS/ArcToolbox/Toolboxes/Spatial Analyst Tools.tbx")
gp.AddToolbox("C:/Program Files/ArcGIS/ArcToolbox/Toolboxes/Spatial Statistics Tools.tbx")
gp.AddToolbox("C:/Program Files/ArcGIS/ArcToolbox/Toolboxes/Conversion Tools.tbx")


###### Functions:

## Function that copies files from one dir to another
## Input data: Source directory and destination directory
def CopyFiles(Source, Destination):
    ## Checks if the destination path exists
    if os.path.exists(Destination) == False:
        ## if not makes the destination folder
        os.mkdir(Destination)
    ## Changes directory to the source
    os.chdir(Source)
    ## Makes a list of all datasets in the source
    DataList = os.listdir(Source)
    ## Iterates through the source data list
    for Data in DataList:
        ## If the source dataset does not exists in the destination folder
        if os.path.exists(str(Destination)+str(Data)) == False:
            ## The file is copied to the destination
            shutil.copy(Data, Destination)
    ## The datalist is deleted
    del DataList

## Function that makes an (output) directory
## Input data: Name of the new dir
def MakeOutDir(DirName):
    ## Checks if the dir to be made exists
    if os.path.exists(str(ws)+str(DirName)+"\\") == False:
        ## If not makes the new dir
        os.mkdir(str(ws)+str(DirName))
    ## makes a variable of the new dir
    Dir = str(ws)+str(DirName)+"\\"
    ## Returns the new dir as a variable
    return Dir

## ArcGIS wants strange names for the field type when adding a field. Here a transformation.
## Input data: Field Type as output of gp.listfields.type
def TransformFieldType(FieldType):
    ## Make sure vatiable is string and in CAPITALS
    FieldType = str(FieldType).upper()
    ## Here goes the conversion
    if FieldType == "STRING":
        ## If it is "STRING" make it "TEXT"
        TransformedFieldType = "TEXT"
    elif FieldType == "SMALLINTEGER":
        ## If it is "SMALLINTEGER" make it "SHORT"
        TransformedFieldType = "SHORT"
    elif FieldType == "INTEGER":
        ## If it is "INTEGER" make it "LONG"
        TransformedFieldType = "LONG"
    else:
        ## Else, leave it as it is...
        TransformedFieldType = FieldType
    ## Unbinds references
    del FieldType
    ## Returns transformed field type
    return TransformedFieldType

## Function that compares rasters using map algebra
## Input data: New Raster, Old Raster and value to be compared
def MapAlgebraCompare(InRasNew, InRasOld, Value, Output):
    ## Makes a folder to write results to
    OutDir = MakeOutDir("mapalgebracompare")
    ## Makes variable for the input datasets
    Input =  str(InRasNew)+";"+str(InRasOld)
    ## Does the map algebra
    exp = "CON ( ( "+str(InRasNew)+" == "+str(Value)+" AND "+str(InRasOld)+" <> "+str(Value)+ " ) , 1 , 0 )"
    ## Do the map algebra operation
    gp.SingleOutputMapAlgebra_sa(exp, str(OutDir)+Output)
    ## Unbind all references
    del OutDir, Input

## Function to polygonize rasters
## Input data: Input Raster and value to group upon
def Polygonize(InRas, Value):
    ## Makes a folder to write results to
    OutDir = MakeOutDir("polydiff")
    ## Makes a name for the output dataset
    OutPoly = str(OutDir)+str(InRas)+".shp"
    ## Convert the rasters to polygons
```

```
        gp.RasterToPolygon_conversion(InRas, OutPoly, "NO_SIMPLIFY", str(Value))
        ## Unbind all references
        del OutDir, OutPoly

    #### Function that calculates areas of polygons
    #### Input data: Polygon dataset
    def CalcArea(InPoly, InFolder):
        ## Makes a folder to write results to
        InPoly = str(InFolder)+str(InPoly)
        ## Add a new field to calc the area in
        gp.AddField_management(InPoly, "AREA", "DOUBLE", "", "", "", "", "NON_NULLABLE", "NON_REQUIRED", "")
        ## Calculate the new field
        gp.CalculateField_management(InPoly, "AREA", "!SHAPE.AREA!", "PYTHON", "")


    #### Function that rasterizes polygon datasets
    #### Input data: Input Polygon, Output raster, Field, Cell Size, Raster Extent
    def RasterizeData(InPoly, OutRaster, Field, CellSize, Extent):
        ## Makes a folder to write results to
        OutDir = MakeOutDir("rasterdata")
        ## Makes a name for the output dataset
        OutRaster = str(OutDir)+"\\"+str(OutRaster)
        ## Load the extent
        tempEnvironment0 = gp.extent
        gp.extent = str(Extent)
        ## Do the polygon to raster operation
        gp.PolygonToRaster_conversion(InPoly, str(Field), str(InPoly[0:3])+"tmp", "MAXIMUM_COMBINED_AREA", "NONE",
CellSize)
        gp.extent = tempEnvironment0
        ## Set zeroes to NoData
        # Try 1
        try:
            gp.Reclassify_sa(str(InPoly[0:3])+"tmp", "VALUE", "0 9999 ; NODATA 9999", OutRaster, "DATA")
            gp.delete_management(str(InPoly[0:3])+"tmp")
        except:
            # Try 2
            try:
                gp.Reclassify_sa(str(InPoly[0:3])+"tmp", "VALUE", "NODATA 9999", OutRaster, "DATA")
                gp.delete_management(str(InPoly[0:3])+"tmp")
            except:
                # Try 3
                try:
                    gp.Reclassify_sa(str(InPoly[0:3])+"tmp", "VALUE", "0 9999", OutRaster, "DATA")
                    gp.delete_management(str(InPoly[0:3])+"tmp")
                except:
                    print "Reclassification failed"

    #### Function that clips rasters by another raster
    #### Input data: Input raster and clip raster
    def RasterClip(InRaster, ClipRaster):
        ## Makes a folder to write results to
        OutDir = MakeOutDir("rasterclip")
        ## Makes a name for the output dataset
        ClipRaster = str(ws)+"rasterdata\\"+str(ClipRaster)
        ## Go to the first lin in the clip raster attribute table
        scur = gp.searchcursor(ClipRaster)
        srow = scur.next()
        ## While there is a row...
        while srow:

            Value = srow.getvalue("VALUE")
            PrettyVal = str("%(#)04d" % {'#' : Value})
            if Value < 9999:
                OutRaster = str(OutDir)+"RasClip_"+str(PrettyVal)
                gp.SingleOutputMapAlgebra_sa("CON ( ( "+str(ClipRaster)+" == "+str(Value)+"
)"+","+str(InRaster)+")", OutRaster, ClipRaster)
            srow = scur.next()

    #### Function that resamples a raster using the majority rule
    #### Input data: Input Raster, Output Raster, New cell size
    def ResampleMajority(InRas, OutRas, NewCellSize):
        ## Makes a folder to write results to
        OutDir = MakeOutDir("resample")
        ## Make a name for the output raster
        OutRas = str(OutDir)+str(OutRas)
        ## Makes a name for the output dataset
        gp.Resample_management(InRas, OutRas, NewCellSize,"MAJORITY")

    #### Function that writes a list to a CSV file
    #### Input data: Input list, output csv file
    def WriteCSV(List, OutFile):
        ## set the name and parameters for the out file
        f = file(r""+str(ws)+str(OutFile)+"","wb")
        ## bind CSV Writer
        w = csv.writer(f, dialect="excel")
        ## write the list to file
        w.writerows(List)
        ## close the file
        f.close()


    ###### Bindings:

    ## Bind all variables
    ws = "C:\\Your_Workspace_Here\\"          # main workspace
    InPoly1993 = "lu_1993.shp"                # old land use dataset
    InPoly2003 = "lu_2003.shp"                # new land use dataset
    InPolyMuni = "muni2003.shp"               # municipality dataset
    ras_1993 = "r1993_10"                     # name for old land use raster
    ras_2003 = "r2003_10"                     # name for new land use raster
    muni_ras = "muni_100"                     # name for municipality raster
    m_a_ras = "m_a_com"                       # name for differences raster
    diff_res = "dif_res"                      # name for resampled differeces raster
    lu_cellsize = 10                                                  # cell size for land use comparison
    res_cellsize = 100                                                # cell size for resampling
    Extent = "10000 300000 280000 625000"       # raster extents
```

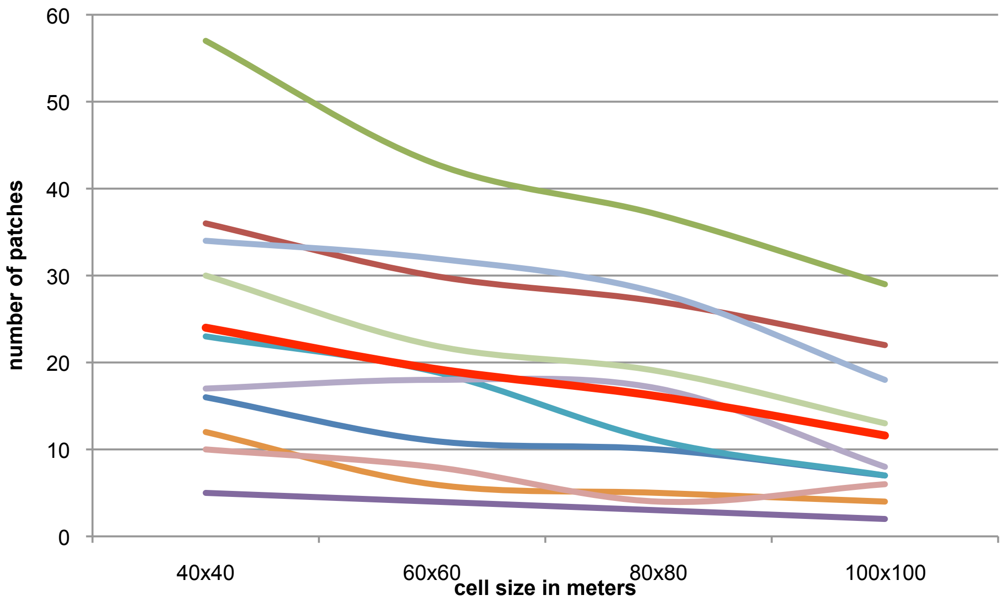
```
## ArcGIS Bindings
gp.Workspace = ws
gp.OverwriteOutput = 1


###### Script:

print "Start"

print "Step 1 / 10"

## Rasterize the land use datasets and the municipality dataset
gp.workspace = str(ws)+"data"
RasterizeData(InPoly1993, ras_1993, "CODE", lu_cellsize, Extent)
RasterizeData(InPoly2003, ras_2003, "CODE", lu_cellsize, Extent)
RasterizeData(InPolyMuni, muni_ras, "CBS_CODE", res_cellsize, Extent)

print "Step 2 / 10"

## Compare the rasters using map algebra
gp.workspace = str(ws)+"rasterdata"
MapAlgebraCompare(ras_2003, ras_1993,  99, m_a_ras)

print "Step 3 / 10"

## Resample the difference raster to the chosen resolution
gp.workspace = str(ws)+"mapalgebracompare"
ResampleMajority(m_a_ras, diff_res, res_cellsize)

print "Step 4 / 10"

## Clip each municipality out of the resampled raster
gp.workspace = str(ws)+"resample"
RasterClip(diff_res, muni_ras)

print "Step 5 / 10"

## Poligonize the map algebra output
gp.workspace = str(ws)+"rasterclip"
rasters = gp.ListRasters("", "")
for x in rasters:
    raster = x
    Polygonize(raster, "VALUE")

print "Step 6 / 10"

## Calculate the area's
gp.workspace = str(ws)+"polydiff"
features = gp.ListFeatureClasses("", "")
MakeOutDir("polyarea")
for x in features:
    feature = x
    FeatureLayer = "muni_"+str(feature[8:12])+"_area.shp"
    Folder = str(ws)+ "polyarea\\"
    try:
        gp.Select_analysis(feature, str(Folder)+str(FeatureLayer),"GRIDCODE = 1")
    except:
        print "Error in selecting the features"
    try:
        InPoly = str(Folder)+str(FeatureLayer)
        gp.AddField_management(InPoly, "AREA", "DOUBLE", "", "", "", "", "NON_NULLABLE", "NON_REQUIRED", "")
        gp.CalculateField_management(InPoly, "AREA", "float('!SHAPE.AREA!')", "PYTHON", "")
    except:
        print "Error in calculating the area"
    try:
        InPoly = str(Folder)+str(FeatureLayer)
        gp.AddField_management(InPoly, "PERIMETER", "DOUBLE", "", "", "", "", "NON_NULLABLE", "NON_REQUIRED",
"")
        gp.CalculateField_management(InPoly, "PERIMETER", "float('!SHAPE.LENGTH!')", "PYTHON", "")
    except:
        print "Error in calculating the area"

print "Step 7 / 10"

## Make lists for the area and perimeter
AreaList = []
PerimeterList = []
path = str(ws)+"polyarea\\"
gp.workspace = path
ds = gp.ListFeatureClasses()
for x in ds:
    dsn = x
    FilePath = str(path)+str(dsn)
    flist = gp.ListFields(FilePath)
    for x in flist:
        fn = x
        if fn.Name == "AREA":
            FieldName = fn.Name
            List = [dsn]
            scur = gp.searchcursor(FilePath,"","","","")
            srow = scur.Next()
            while srow:
                val = srow.getvalue(FieldName)
                List.append(val)
                srow = scur.Next()
            AreaList.append(List)
        if fn.Name == "PERIMETER":
            FieldName = fn.Name
            List = [dsn]
            scur = gp.searchcursor(FilePath,"","","","")
            srow = scur.Next()
            while srow:
                val = srow.getvalue(FieldName)
                List.append(val)
                srow = scur.Next()
            PerimeterList.append(List)
```

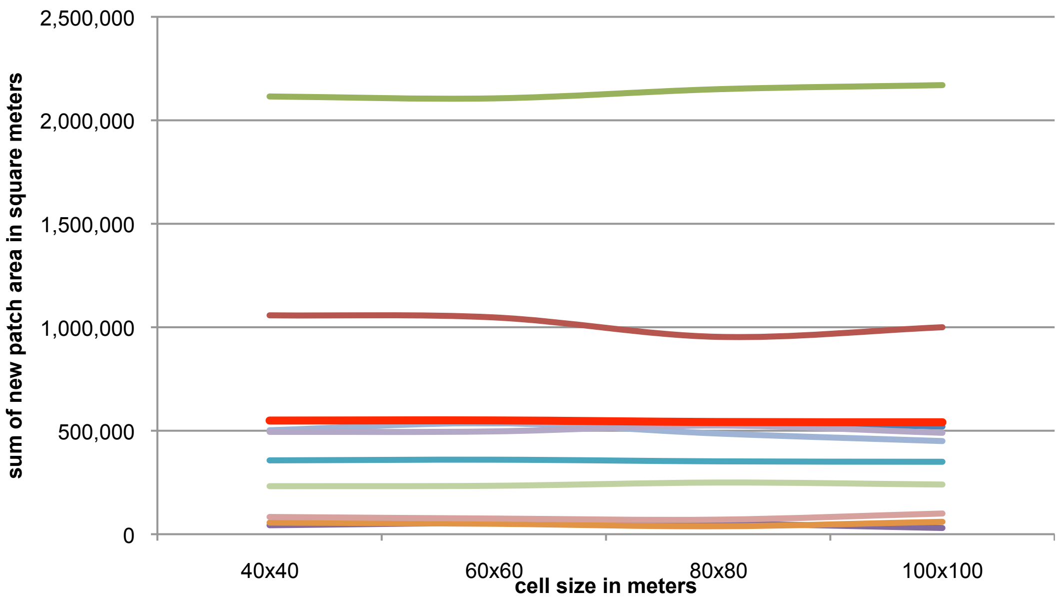
```
    print "Step 8 / 10"

    ## Combine area and perimeter lists
    ListLen1 = len(AreaList)
    ListLen2 = len(PerimeterList)
    if ListLen1 != ListLen2:
        print "ERROR! List lengths are not equal, cannot interleave"
    else:
        PerimeterAreaList = []
        n1 = 0
        while n1 < ListLen1:
            TempList = []
            TempList.append(AreaList[n1][0])
            n2 = 1
            ListLen3 = len(AreaList[n1])
            while n2 < ListLen3:
                PARatio = PerimeterList[n1][n2] / AreaList[n1][n2]
                TempList.append(PARatio)
                n2 = n2 + 1
            PerimeterAreaList.append(TempList)
            n1 = n1 + 1

    print "Step 9 / 10"

    ## Calculate the patch statistics in a list
    StatList = []
    header = []
    StatisticsList                                                                                          =
["muni","cbs_code","len","a_sum","a_mean","a_stdev","a_min","a_max","p_sum","p_mean","p_stdev","pa_ratio","pa_min","pa
_max"]
    for x in StatisticsList:
        header.append(x)
    StatList.append(header)
    n = 0
    ListLen = len(AreaList)
    while n < ListLen:
        values = []
        values.append(AreaList[n][0])
        MuniNum = AreaList[n][0][5:9]
        if MuniNum.startswith("0") == True:
            MuniNum = MuniNum[1:4]
        if MuniNum.startswith("0") == True:
            MuniNum = MuniNum[1:3]
        if MuniNum.startswith("0") == True:
            MuniNum = MuniNum[1:2]
        values.append(AreaList[n][0][5:9])
        ## Stats for Area List
        try:
            values.append(len(AreaList[n][1:]))
        except:
            print "Error calculating the length"
            values.append("")
        try:
            values.append(stats.lsum(AreaList[n][1:]))
        except:
            print "Error calculating the sum"
            values.append("")
        try:
            values.append(stats.lmean(AreaList[n][1:]))
        except:
            print "Error calculating the mean"
            values.append("")
        try:
            values.append(stats.lstdev(AreaList[n][1:]))
        except:
            print "Error calculating the standard deviation"
            values.append("")
        ## Min / Max for Area list
        try:
            values.append(min(AreaList[n][1:]))
        except:
            print "Error calculating the min of AList"
            values.append("")
        try:
            values.append(max(AreaList[n][1:]))
        except:
            print "Error calculating the max of AList"
        ## Stats for Perimeter List
        try:
            values.append(stats.lsum(PerimeterList[n][1:]))
        except:
            print "Error calculating the sum of PList"
            values.append("")
        try:
            values.append(stats.lmean(PerimeterList[n][1:]))
        except:
            print "Error calculating the mean of PList"
            values.append("")
        try:
            values.append(stats.lstdev(PerimeterList[n][1:]))
        except:
            print "Error calculating the standard deviation of PList"
            values.append("")
        ## Average for Perimeter-Area List
        try:
            values.append(stats.lmean(PerimeterAreaList[n][1:]))
        except:
            print "Error calculating the mean of PAList"
            values.append("")
        ## Min / Max for Perimeter-Area List
        try:
            values.append(min(PerimeterAreaList[n][1:]))
        except:
            print "Error calculating the min of PList"
            values.append("")
        try:
            values.append(max(PerimeterAreaList[n][1:]))
```

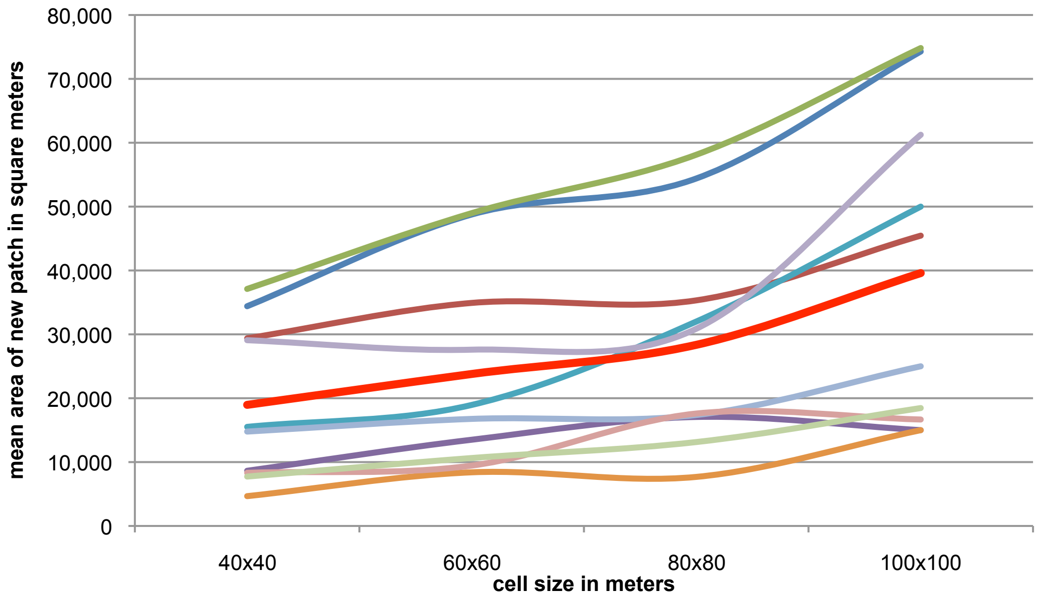
```
    except:
        print "Error calculating the max of PList"
        values.append("")
    StatList.append(values)
    n = n +1

print "Step 10 / 10"

## Write  the statistics list to a csv file
WriteCSV(StatList, "stats.csv")

print "Finished"

############################################################
```

Appendix H Effects of cell size on the refined calculation

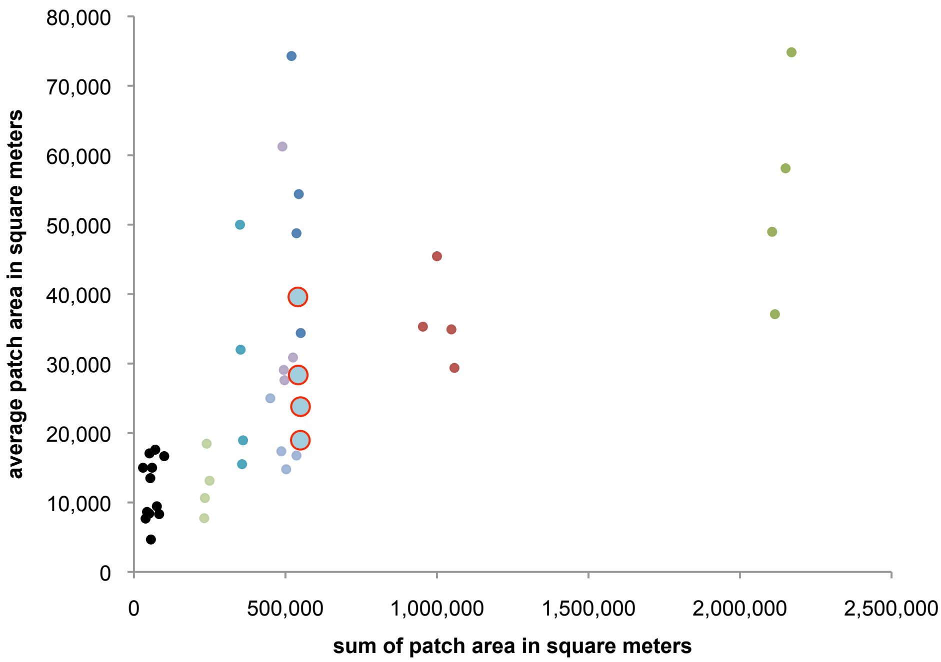
To get an insight of the effects of cell size on the number and size of patches that come out of the calculation three graphs and one scatter diagram have been plotted. These plots contain the observed values for the ten selected test municipalities. In the graphs the number of patches, the sum of patch area and the average patch area are plotted against the different cell sizes. In the scatter diagram the average patch area is plotted against the total sum of patch area. Each dot represents a cell size (overall, higher cell size means higher average patch size) and each colour represents a test case. In all graphs the bold red line or bold red dots represent the average values for the test municipalities.







mean area of new patch in square meters
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
40x40
60x60
80x80
100x100
cell size in meters



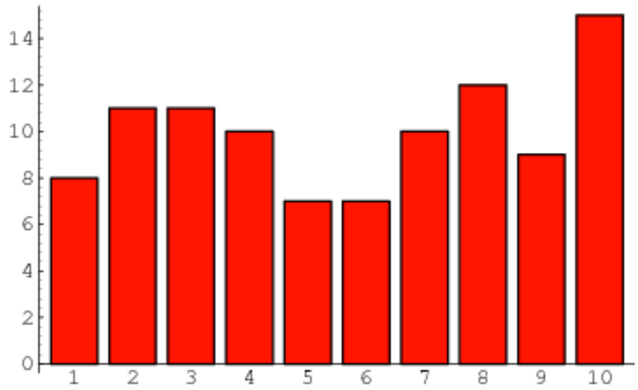
average patch area in square meters
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
500,000
1,000,000
1,500,000
2,000,000
2,500,000
sum of patch area in square meters

Appendix I Statistics Reference

Histogram

A histogram is a bar chart that splits the observations in classes by value. The values of the observations are displayed on the x-axis and the frequencies of observation of the same class of values are plotted on the y-axis. A high bar thus means that there are many observed values in the class that the bar represents.

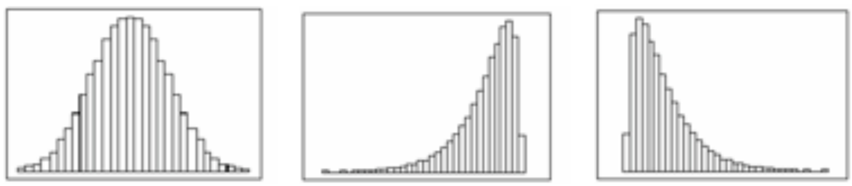
Example histogram: values on the x-axis, frequencies on the y-axis



Source: (Weisstein, 2010b)

A histogram also provides valuable insights in the shape of the distribution of observations. If the values compose a bell shaped histogram, the values are normally distributed (in a perfect normal distribution the mean and median have the same value). If the tail on the left side is longer, the distribution is skewed to the left or negative skew. If the tail on the right side is longer, the distribution is skewed to the right or positive skew.

Symmetric and skewed frequency distributions

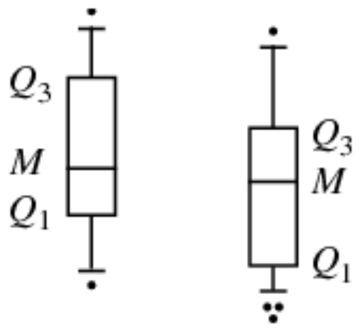


Symmetric Bell shaped (left) Skewed to the Left (middle) Skewed to the Right (right)
Source: (Penn State University Statistics Department, 2007)

Box and Whisker diagrams

Box-and-whisker diagrams visually represent the distribution of observations within a group of observations (image below). Box-and-whisker diagrams display differences between population and they are non-parametric: they can be used without underlying statistical assumptions on the data (Weisstein, 2010a). If all observations are ordered from small to large, the middle value is called the median (indicated with the M in the image below). Q1 and Q3 represent the first and third quartile borders (median is the second quartile border) at 25 and 75 percent of the observations. The area between Q1 and Q3 is called the inter quartile range (IQR), but usually it is referred to as "the box". The lines above Q3 and below Q1 are called the "whiskers". Although the definition of the ends of the whiskers can differ they are usually representing the maximum and the minimum value of the range of observations as long as they are not further than 1.5 IQR away from the box. If values are more than 1.5 IQR away from the box these data points are usually called "outliers" and represented by dots away from the whisker (Vocht, 2004; Weisstein, 2010a).

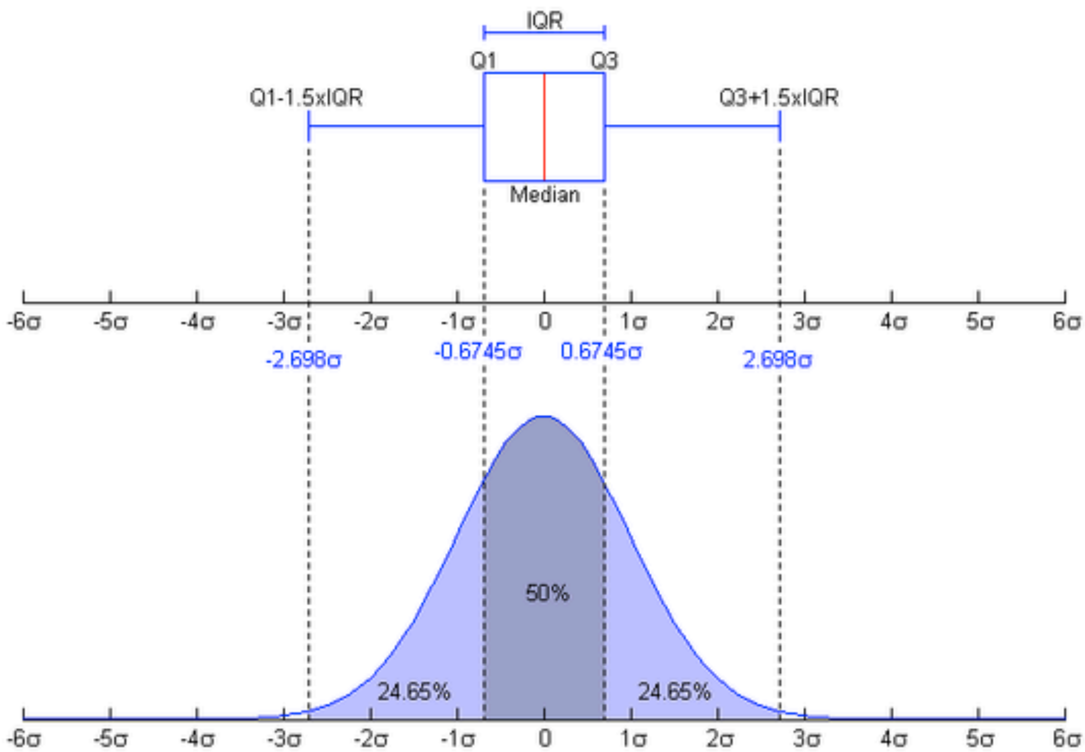
Example of a box-and-whisker diagram



Source: (Weisstein, 2010a)

The box-and-whisker diagram provides valuable information about the distribution of the values of a group of observations. When flipped horizontally a box plot can be compared to a histogram or a distribution graph.

Box-and-whisker diagram compared to a normal distribution



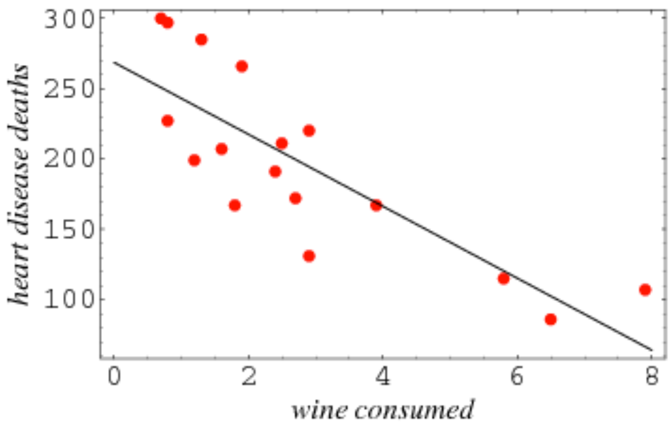
Source: (Jhguch, 2006)

Skewness of the observations can also be derived from the box-and-whisker diagram. If the distribution of observations is positively skew, the median is relatively low in the box. With a negative skew distribution, the median will be relatively high in the box. Using box plots the values for the metrics will be analysed one by one.

Scatter Diagrams

A scatter diagram can be used to plot two independent variables or one dependent and one independent variable in one plot, to examine if there is correlation between these two variables. The independent variable is represented on the x-axis and the dependent variable (if any, else the other independent variable) on the y-axis. Each dot in the scatter diagram represents a pair of x and y values for one case or observation. If there is a clear linear pattern in the scatter plot a regression line can be fitted through the data points. The aberration of the data points from their by the regression line predicted values is called the residual of the data points.

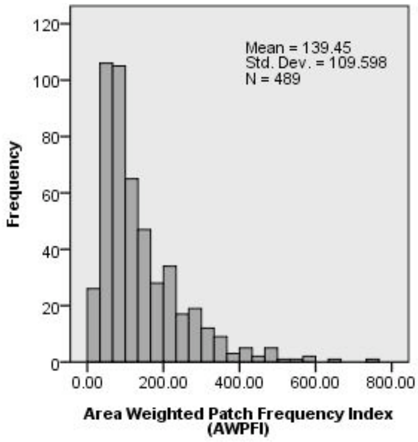
Example scatter diagram

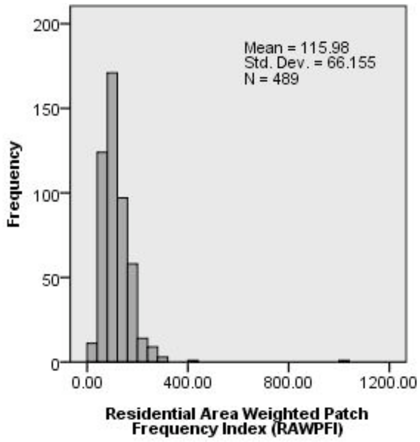


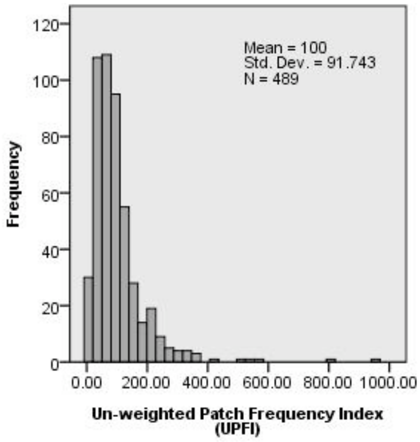
The scatter diagram above plots wine consumption (in litres of alcohol from wine per person per year) against deaths from heart disease (in deaths per 100,000 people) for 19 developed nations.
Source: (Renze & Weisstein, 2010)

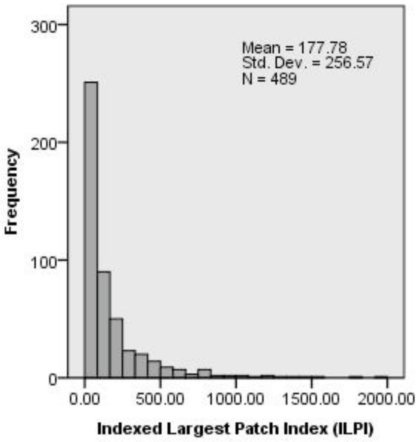
Appendix J Histograms for the metric values

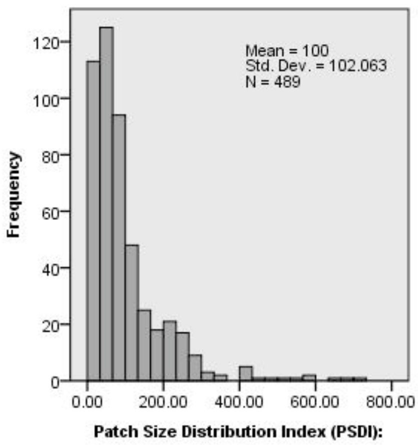
The histograms below that have been used to analyse the frequency distributions of values for the different metrics.

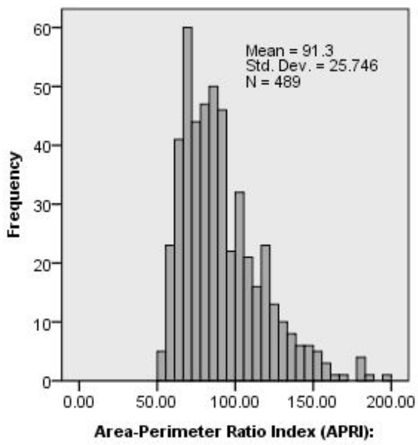












Appendix K Scatter diagrams for National Landscapes

The scatter diagrams comparing the metric value to the percentage of National Landscape are displayed below. These scatter diagrams have been omitted in the main text as they hardly show any pattern.